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MEDIAN BARRIERS
ONE YEAR'S EXPERIENCE
AND
FURTHER CONTROLLED FULL SCALE TESTS

By

J.L. Beaton

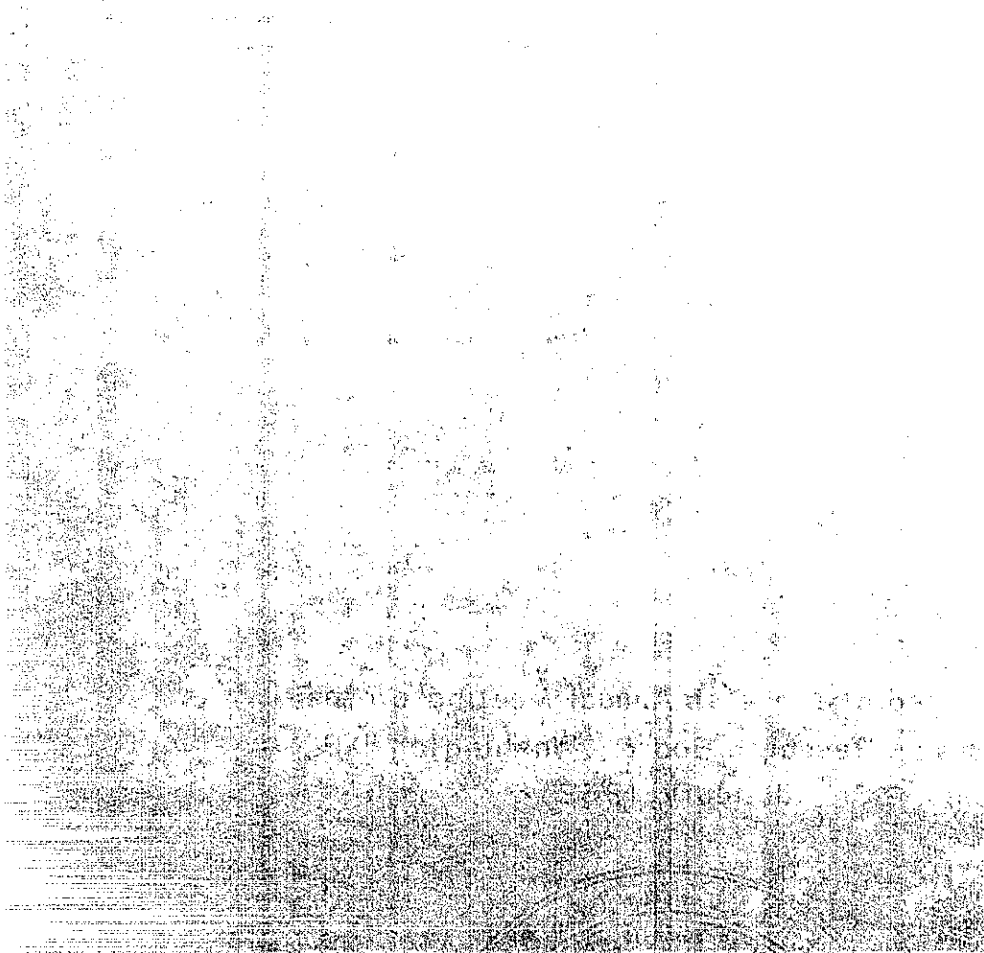
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MEDIAN BARRIERS: ONE YEAR'S EXPERIENCE AND
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SYNOPSIS

The development of two types of barriers for use in the medians of California freeways was reported in January 1960¹.

As outlined in that report, it was planned to continue studying these two barriers under actual operating conditions.

This report covers one year operation and additional full scale collision tests of cable-chain link barriers. The before and after operational studies indicate that:

- (1) The barriers were successful but there is need for some improvement.

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- (2) The total accidents increased after the barriers were installed, but the fatalities from head-on collisions were virtually eliminated.
- (3) The maintenance and repair cost of the cable-chain link barrier was more than the metal beam barrier but that this was offset by the higher first cost of the metal beam barrier.

Controlled collision tests resulted in an improved design of the cable-chain link barrier.

INTRODUCTION

In the summer of 1959, two types of median barriers were developed and tested for use on California freeways. These were the cable-chain link barrier, hereafter referred to as "cable", and the blocked-out metal beam barrier, hereafter referred to as "beam". Details of the barriers, and tests leading to their adoption, were reported in Highway Research Board Bulletin 266¹.

Since the latter part of 1959, several miles of median barriers conforming to these developed designs have been placed on California freeways. The status of California's barrier construction program as of September 1961 was:

	<u>Net Miles of Barrier-Divided Highway</u>		
	<u>Cable</u>	<u>Beam</u>	<u>Total</u>
Constructed	31.5	16.8	48.3
Under Construction	47.0	15.1	62.1
Budgeted (Preliminary Report received)	<u>38.5</u>	<u>11.6</u>	<u>50.1</u>
Total	117.0	43.5	160.5

In order to compare the performance of the two types of barrier, the first contracts were split, providing some of each type in each contract. These are referred to as test sections. One test section was on the Santa Ana Freeway in Los Angeles where 3.17 miles of cable barrier were erected end-to-end with 2.57 miles of beam barrier, and the other test section was on the Nimitz Freeway in Oakland where 3.87 miles of cable barrier were erected end-to-end with 2.87 miles of beam barrier. Before-and-after accident records on these test sections have been examined. In addition, a complete operational

study, including both construction and maintenance problems, has been made.

These studies indicated that (1) improvements in design details of the cable barrier were desirable and (2) more information was needed concerning the effect of the cross-section and profile of the highway surface on the trajectory of a fast moving automobile.

The barrier deficiencies were analyzed and certain changes made. The corrected designs then were tested by a new series of controlled full scale collisions. Exhibit 1 in the Appendix shows an over-all view of the collision test site. The results of both the operational study and the controlled tests are given in this report. Plates outlining the details of each test are included in the Appendix.

SUMMARY

- (1) Head-on accidents were virtually eliminated by the barriers. On the Santa Ana and Nimitz test sections, there were 49 cross-median accidents in the "before" period, including 8 fatal accidents, and there were two cross-median accidents in the "after" period, one of which was fatal.
- (2) Total accidents and injury-accidents increased in the locations where barriers were installed.
- (3) The freeway test sections with the cable barrier experienced a smaller increase in the over-all accident rate than did those with the beam barrier. There was no proof that the accidents involving the cable barrier were less severe. However, the findings of the controlled impact tests indicated that high speed collisions with the cable barrier would result in much less severe injury to vehicle occupants, and it is believed that in general the accidents involving the cable barrier are less severe.
- (4) The maintenance cost of the cable barrier is considerably higher than that of the beam barrier. First cost of the beam barrier is much greater than the cable barrier. It would require some 19.5 years for the total expenditure to balance.
- (5) More accidents are evident involving the cable barrier. The proportion of single-vehicle accidents is much higher with the cable barrier than with the beam barrier. There is no indication that drivers are more reluctant to swerve into the beam barrier, but there are indications that there may be more "hit-and-drive-away" accidents involving the cable.

- (6) There was little difference in the cable barrier accident rate between the sections with 12- and 22- foot medians, and the maintenance cost per mile was essentially the same. There was no evidence to indicate that the deflection of the cables led to collisions by permitting momentary encroachment in the opposing lanes.
- (7) In installations other than the test sections, two vehicles climbed up and over the cable barrier and there were indications that others made partial climbs up the barrier.

Subsequent controlled collision tests indicated this tendency could be minimized by removing the lower cable from the original design. The revised design is shown on Exhibit 2 (Appendix).

- (8) In addition to the two vehicles that climbed the cable barrier two vehicles jumped barriers. One on the Santa Ana test section was apparently due to the car striking a curb in front of the barrier. The other was not on the test sections and was judged to be the result of the barrier being too low in relation to the plane of the roadway superelevated surface,

Subsequent controlled collision tests indicate that a 30 inch high barrier should be placed at or before the point of intersection of the shoulder slope and ditch slope. If it is necessary to place the barrier down the ditch slope, then it should be placed no further down the slope than will result in the top of the barrier being at least 27 inches above a horizontal projection from the point of intersection of the slopes.

- (9) Analysis of controlled collision test results indicate that the cable in a cable-chain link barrier should be placed no higher than 33 inches above and no lower than 27 inches above the ground line (or surface of control elevation).
- (10) Details of design of the cable barrier should be such that no fixed restraints exist insofar as the cable clamps or chain link fabric are concerned. A design incorporating these features as well as improvements for maintenance purposes is shown on Exhibit 2.
- (11) Expanded metal for a more effective headlight screen substituted in place of the chain link fabric makes little change in the cable barrier performance.

OPERATIONAL EXPERIENCE

Effectiveness of Barriers in Preventing Cross-Median Accidents and Fatal Accidents

Both types of barrier have proven effective in accomplishing the purpose for which they were designed. Including installations in addition to the "test-sections", they have been struck hundreds of times, and only two head-on accidents have occurred at locations where they are in place. The two head-on accidents were the result of vehicles which climbed or jumped clear over the barrier. Only one of these head-on accidents occurred within an experimental section. The other happened on the Ventura Freeway.

In addition to the above two cross-overs, which resulted in head-on collisions, two other cross-overs took place. One was a small sports car which passed through the cable barrier under the top cable; the other resulted from a car traveling at high speed up the superelevation of a curve and jumping high enough to clear the top cable. The barrier in this latter case was located in the bottom of the ditch of a typical "saw-tooth" cross-section. Only the first of these accidents was within an experimental section.

Three partial cross-overs occurred during the year. Two were within an experimental section, both of which involved truck-trailer combinations with the beam barrier on the Nimitz Freeway. In each case the barrier failed, but the trucks were stopped short of serious encroachment in the opposing lane. The third took place on the Ventura Freeway and involved a cable barrier. The automobile in this case came to rest on top of the barrier half on one side and half on the other, but entirely within the median.

Effect of Barriers on Over-all Accident Record, by Type of Barrier

As described in the introduction, test sections of both types of barrier were erected on the Santa Ana Freeway and the Nimitz Freeway for the purpose of comparing the effectiveness of the two types of barrier.

Although there is no way of being sure that the differences between sections are attributable solely to the difference in type of barrier, it was thought that as many extraneous factors as possible would be eliminated by an end-to-end comparison on the same freeway where traffic volume remains approximately uniform, and, in fact, the very same vehicles pass by first one type of barrier and then the other.

Comparisons between cable barrier on one freeway and beam barrier on another should be interpreted very cautiously, because there are so many other potential variables which could affect accident rates that the difference owing to type of barrier can be smothered in irrelevancies.

The Santa Ana test sections were between the Long Beach Freeway and Buhman Avenue, and the Nimitz Freeway test sections were between High Street and Washington Avenue. These are both 6-lane freeways with 12-foot medians. The average daily traffic was between 90,000 and 100,000 on all sections. Grades are practically level and alignment is excellent.

Before-and-after statistics, using one year prior to construction as the "before" period, and one year after completion as the "after" period (the period during construction is omitted) are shown in Table 1 for the Santa Ana test sections and Table 2 for the Nimitz test sections. In addition there is included Table 3 for a section of the Hollywood Freeway.

TABLE 1
BEFORE AND AFTER RECORD
SANTA ANA FREEWAY TEST SECTIONS

<u>All Reported Accidents</u>							
		<u>Before</u>		<u>After</u>		<u>Change</u>	
	<u>Miles</u>	<u>No.</u>	<u>Rate*</u> <u>Per MVM</u>	<u>No.</u>	<u>Rate</u> <u>Per MVM</u>	<u>in Rate</u>	<u>%</u>
Cable	3.17	120	1.08	153	1.30	+0.22	+20
Beam	2.57	74	0.80	107	1.12	+0.32	+40

<u>Injury-Accidents (Including Fatal)</u>							
		<u>Before</u>		<u>After</u>		<u>Change</u>	
	<u>Miles</u>	<u>No.</u>	<u>Rate</u> <u>Per MVM</u>	<u>No.</u>	<u>Rate</u> <u>Per MVM</u>	<u>in Rate</u>	<u>%</u>
Cable	3.17	55	0.49	56	0.48	-0.01	-2
Beam	2.57	26	0.28	41	0.43	+0.15	+53

The following points are noted concerning the Santa Ana test sections:

- (1) Before barriers were erected on either section, the section where beam barrier was later erected had a much lower accident rate than the section where the cable barrier was erected.
- (2) The total accident rate increased significantly after erection of the barriers, on both sections.

* Rate per MVM is the number per million vehicle-miles. An injury-accident rate of 0.49 per MVM shows that more than two million car-miles (the total life of about 30 cars) of travel are accumulated for each accident serious enough to cause minor injuries to the occupants.

- (3) The percentage increase on the section with the beam barrier was much greater than the percentage increase on the section with the cable barrier.
- (4) Although total reported accidents increased where the cable barrier was installed, accidents severe enough to cause injuries did not increase. Where the beam barrier was installed, the injury accident rate increased by 53%. This increase cannot be directly related to cars which crashed into the barrier, however.

TABLE 2
BEFORE AND AFTER RECORD
NIMITZ FREEWAY TEST SECTIONS

<u>All Reported Accidents</u>							
		<u>Before</u>		<u>After</u>		<u>Change</u>	
	<u>Miles</u>	<u>No.</u>	<u>Rate Per MVM</u>	<u>No.</u>	<u>Rate Per MVM</u>	<u>in Rate</u>	<u>%</u>
Cable	3.87	185	1.51	250	1.90	+0.39	+26
Beam	2.87	146	1.55	216	2.13	+0.58	+37

<u>Injury-Accidents (Including Fatal)</u>							
		<u>Before</u>		<u>After</u>		<u>Change</u>	
	<u>Miles</u>	<u>No.</u>	<u>Rate Per MVM</u>	<u>No.</u>	<u>Rate Per MVM</u>	<u>in Rate</u>	<u>%</u>
Cable	3.87	71	0.58	105	0.80	+0.22	+38
Beam	2.87	*	*	95	0.94	*	*

* Where the beam barrier was installed, there was a change in jurisdiction of enforcement agencies between the "before" and "after" periods. Because of a change in methods of reporting, and in definition of "injury", the injury-accident rate in the before period is not known.

The following points are noted concerning the Nimitz test sections:

- (1) The over-all accident rates were about equal on both sections before the barriers were erected on either section.
- (2) The accident rates increased significantly after erection of the barriers, on both sections.
- (3) The increase in accident rate was somewhat greater on the beam section than on the cable section (37% against 26%).
- (4) During the "after" period, 42% of the reported accidents on the cable section resulted in injuries, and 44% of the reported accidents on the beam section resulted in injuries. This is about the normal ratio for all freeways.

TABLE 3

BEFORE AND AFTER RECORD
HOLLYWOOD FREEWAY
BETWEEN HARBOR FREEWAY AND BENTON WAY

Beam Barrier 1.68 miles. ADT --- 190,000

	<u>Before</u>		<u>After</u>		<u>Change</u>	
	<u>No.</u>	<u>Rate</u>	<u>No.</u>	<u>Rate</u>	<u>Rate</u>	<u>%</u>
All Accidents	242	2.10	266	2.21	+0.11	+5
Injury Accidents	158	1.37	155	1.29	-0.08	-6

While not included in the test sections, this installation is listed to illustrate the effect of extremely congested traffic. The following points are noted regarding the Hollywood Freeway beam barrier installation:

- (1) The rates were high* before and after. This is probably characteristic of extremely congested freeways.
- (2) The barrier did not affect the rates, either overall or injury.
- (3) The ratio of injury accidents to total accidents, 60%, is very high. It is possible that many non-injury accidents are being overlooked on this section.

The barriers have generally resulted in an increase in overall accidents, except on the Hollywood Freeway where the volume

* While these rates are considered high for urban freeways, they are still only about 1/3 of the rate on urban arterials other than freeways.

is 190,000. An earlier study² had indicated that barriers would increase accidents on roads where the volume is less than 130,000.

The percentage increase in both the all-accident rate and injury-accident rate was greater where the beam barrier was placed than where the cable barrier was placed, although the sample is so small and other unaccounted-for differences in rates are so large that these differences could be due to reasons other than difference in barrier types.

It may be significant that the rise in accidents on the cable barrier section of the Santa Ana was not accompanied by a rise in the injury-accident rate. However, the rise in injury accidents on the Nimitz cable section was just as great as the rise in all-accidents on this section.

The ratio of all accidents to injury-accidents lies in the expected range of 2.2 to 2.8 in the before and after samples for both types of barrier in the test sections. This is significant in that it shows that the increase in reported accidents is not comprised of mere fender-benders or fence-scrappers.

Accidents Involving the Median

A. Although head-on accidents were virtually eliminated by both types of barrier, it has been seen that in general there was a rise in accident rates where the barriers were installed on freeways having traffic volume less than 130,000 vehicles per day. One explanation, of course, would be that without a barrier many vehicles are able to encroach on the median without suffering a reportable accident, whereas after the barriers are installed, they strike a barrier. Table 4 shows the relation between the number of cars hitting the barrier and the rise in accidents when barriers are installed.

TABLE 4

PROPORTION OF INCREASE IN ACCIDENT RATES
ACCOUNTED FOR BY ENCROACHMENT IN MEDIAN

	Over-all Increase in <u>Accidents</u>	<u>Accidents "Involving" Median</u>			Proportion of Increase Accounted for by Accidents Involving the Median
		<u>Before</u>	<u>After</u>	<u>Increase</u>	
	<u>Rate Per MVM</u>	<u>Rate Per MVM</u>	<u>Rate Per MVM</u>	<u>Rate Per MVM</u>	
Santa Ana Cable	0.22	0.17	0.33	0.16	73%
Santa Ana Beam	0.32	0.23	0.15	(0.08) ^D	0
Nimitz Cable	0.39	0.22	0.53	0.31	80%
Nimitz Beam	0.58	0.19	0.52	0.33	57%

()^D = Decrease

It can be seen in Table 4 that a considerable proportion (57% to 80%) of the increase can be accounted for by collisions with the barrier except in the case of the Santa Ana Beam Section. Before reaching any conclusions, note that the over-all increase in the accident rate on the Santa Ana beam section was 50% greater than the increase on the Santa Ana cable section. The decrease in rate of accidents involving the median on the Santa Ana beam section is one of the inexplicable things that are frequently encountered when making a statistical study involving small numbers.

B. Events associated with barrier collisions.

As Table 4 shows, a lot more drivers are getting involved with the median than there were before the barriers were erected. What the table does not show is the number of times the median was violated in the "before" period with no resulting accident.

There has been speculation that people are deliberately driving into the cable barrier on the theory that it is softer than the car ahead. In an effort to explore this possibility, Table 5 was prepared. This table classifies the accidents involving the barrier according to events preceding the collision. There is also a subjective classification in the right-hand two columns as to whether the vehicle was deliberately or involuntarily driven into the barrier. This classification represents the analyzer's judgment, based upon reporting officer's opinion, statements by the drivers, and statements of witnesses, as well as upon the events.

In addition to data on the test section of cable-chain link barrier, information is also included concerning a cable-chain link installation on the Ventura Freeway, so as to point out certain differences probably influenced by different median design features.

The following points are noted regarding Table 5:

- (1) On the test sections, 58% of accidents involving the beam barrier were 2-or-more-car accidents, whereas only 39% of accidents, involving the cable barrier, were 2-or-more-car accidents. On the Ventura Freeway, only 20% involved more than one vehicle.
- (2) About one-fifth of the median barrier collisions were deliberate, sort of a "fielder's choice", in which the driver thought he was choosing the lesser consequences. This ratio was the same for the cable barriers as it was for the beam barriers, although on the Ventura Freeway only 2 "deliberate" swerves resulted in reported accidents. This freeway has 8- foot paved

TABLE 5
MEDIAN BARRIER ACCIDENTS CLASSIFIED BY ASSOCIATED EVENTS
(One Year After Construction)
(Test Sections and Ventura Freeway)

		Avoid Rear-End Accidents		Unsafe Lane Change		Knocked into Barrier By		Ran Into Barrier After		Drifted Into Barrier (Sleep, Drink, Inattention)		Misc. Known Action		Deliberate Action		Involuntary Action		Total Accidents
Single Vehicle	Multi-Vehicle	Deliberate Action	Lost Control	Avoiding	Making	Side-swipe	Rear-End	Side-swipe	Rear-End	Erratic Driver				Unknown				
CABLE-CHAIN LINK BARRIER																		
Santa Ana	23	15	8	2	1	3	1	1	3	2	2	8	5	11	27	38		
Nimitz	37	23	5	8	0	2	5	0	1	8	3	14	2	11	49	60		
(No.)	60	38	13	14	1	5	6	1	4	10	5	22	7	22	76	98		
TOTAL (%)	61	39	13	15	1	5	6	1	4	10	5	23	7	22	78	100		
Ventura	21	5	2	0	1	2	2	0	0	1	5	4	9	2	24	26		

BLOCKED-OUT METAL BEAM BARRIER																		
Santa Ana	5	7	1	5	2	1	0	0	1	0	0	0	1	2	10	12		
Nimitz	16	22	7	11	5	2	5	0	2	0	1	5	0	10	28	38		
(No.)	21	29	8	16	7	1	5	0	3	0	1	5	1	12	38	50		
TOTAL (%)	42	58	16	32	14	2	10	-	6	-	2	10	2	24	76	100		

shoulders in the median, whereas the test sections on the Santa Ana and Nimitz Freeways have curbs and only a 6- foot half-width.

- (3) On the test sections, 86% of collisions with the beam barrier and 55% of collisions with the cable barrier were associated with maneuvers such as rear-end and sideswipe collisions or near-collisions.
- (4) On the test sections, 22% of the cable barrier collisions and 4% of the beam barrier collisions were due to erratic driving, drifting, and unknown reasons. "Erratic Driving" are cars which were observed by witnesses to be driving erratically for some time before colliding with the barrier.
- (5) "Unknown, misc., drifting, and sleep" accidents (nearly all involving only one car) accounted for 19 of the 26 collisions with the cable barrier on the Ventura Freeway. This relatively high proportion is owing more to a lack of other kinds than to an excessive number of these kinds. The fact that there were only 7 accidents associated with rear-end and sideswipe maneuvers is probably attributable to the shoulders and absence of curbs. It was also determined that 16 of the 26 on the Ventura Freeway were at night.

C. Repeated crash tests demonstrated conclusively that when a car collides with the cable barrier there is far less shock and that there should be far fewer injuries for a given number of barrier collisions. The first year's experience on the test sections showed the following:

TABLE 6
SEVERITY OF REPORTED ACCIDENTS INVOLVING MEDIAN BARRIERS

	Total No. of Vehicles Colliding With Barrier	Collisions in Which Occupants were Injured			Fatal Accidents	
		Seri- ously	Minor Wounds, Contu- sions	Total	No.	Remarks
Santa Ana Beam	12	0	3	3	0	
Santa Ana Cable	38	3	9	12	1	x-median, head-on
Nimitz Beam	38	7	11	18	2	1 suicide, 1 truck driver ejected when truck hit barrier
Nimitz Cable	60	8	19	27	2	1 motorcycle, 1 spinning car, occupants ejected

It is noted that experience of one year does not show conclusively that collisions with the cable barrier are less severe than with the beam. This is contrary to expectation. Observations and actual measurements of test crashes showed that deceleration rates, which are closely related to injury potential, are significantly less with the cable. There were so few serious injuries involving collisions with either type that it is believed that the measured evidence of physical tests outweighs the statistical evidence, in which chance plays a major part.

Maintenance records show that the number of repairs of the cable barrier greatly exceeds the number of reported accidents involving the barrier. On the other hand, there have been reported accidents involving the beam barrier that did not require repairs.

TABLE 7

COMPARISON OF REPORTED ACCIDENTS WITH BARRIER REPAIRS

	<u>Reported Accidents Involving Barrier</u>	<u>No. of Repairs</u>
Santa Ana Beam	12	25
Santa Ana Cable	38	60
Nimitz Beam	38	37
Nimitz Cable	60	91

Table 7 shows that collisions were much more likely to damage the cable barrier, and that for a given number of reportable accidents there is more disruption to traffic caused by barrier repairs, as well as additional maintenance cost. It does not necessarily show that there were more "drive-away" or hit-and-run collisions with either type, but it does show definitely that about one-third of the collisions with the cable barrier were so minor that the vehicles were able to drive away.

Construction and Maintenance CostsA. Initial Cost

By the end of the 1960-61 fiscal year, approximately 49 miles of barrier had been installed. Average unit prices for the barriers were as follows:

	<u>Per Lineal Foot</u>	<u>Per Mile</u>
1. Single Metal Beam	\$ 5.84	\$ 30,700
2. Double Metal Beam	8.31	43,800
3. Double Metal Beam on Steel Posts (Structures)	14.53	----
4. Cable-Chain Link	3.25	17,100

The unit price of beam barrier was 2.6 times that of the cable barrier. In later contracts, the unit price of cable barriers has declined.

B. Maintenance Costs

Maintenance costs of the two types of barrier during the one year period after construction are shown in Table 8. The average yearly cost of repair is shown in terms of cost per mile, cost per accident, and cost per million vehicle-miles of travel or exposure. The unusually large cost per mile for the beam barrier on the Nimitz Freeway was due to the two accidents involving truck-trailer combinations.

The annual cost per mile of \$2,078 for the cable barrier was 2.9 times the \$720 per mile cost of the beam barrier. With a \$1358 per mile difference in the annual cost of barrier repairs, it requires 19-1/2 years for the damage cost of the fence barrier to equal the difference in construction cost between the two barriers. However, it should be noted that approximately 60% of the damage costs have been recovered, hence the actual difference in the maintenance costs to the State was \$540 per mile.

At \$540 per mile per year, it would require 49-1/2 years to make up the difference of \$26,700 per mile in initial cost.

More important than cost is the hazard to both maintenance workers and the traveling public of continual maintenance in the median. There is also a certain amount of congestion caused by such operations. In this regard, comparison of the two types should include the bulkiness of equipment and size of crew required, and the time per job, as well as the number of repairs required. The width of median is also important in this respect.

TABLE 8
COST OF BARRIER REPAIRS FOR ONE YEAR AS REPORTED BY MAINTENANCE DEPARTMENT

<u>Cable Chain Link Barrier</u>						
<u>Freeway</u>	<u>Length</u>	<u>Million Vehicle-Miles</u>	<u>No. of Repairs</u>	<u>Total Cost (One Year)</u>	<u>Cost Per Repair</u>	<u>Cost Per Mile-Year</u>
Nimitz	3.87	131.65	91	\$ 6,879.53	\$ 75.60	\$1,777.66
Santa Ana	3.17	117.21	60	7,848.16	130.80	2,475.76
Sub-Total	7.04	248.86	151	14,727.69	97.53	2,092.00
Ventura	2.35	78.06	43	4,782.00	111.21	2,034.89
TOTAL	9.39	326.92	194	\$19,509.69 ⁽¹⁾	\$100.57	\$2,077.71
<u>Blocked-Out Metal Beam Barrier</u>						
Nimitz	2.87	101.30	37	\$ 3,658.41	\$ 98.88	\$1,274.71
Santa Ana	3.29	127.66	21	1,205.26	57.45	366.20
Sub-Total	6.16	228.96	58	4,863.67	83.90	780.00
Bayshore	1.43	53.42	4	599.88	149.97	419.50
TOTAL	7.59	282.38	62	\$ 5,463.55 ⁽¹⁾	\$ 88.10	\$ 720.00
						\$19.35
						\$52.26
						66.96
						59.18
						61.26
						\$59.68
						\$36.11
						9.50
						21.25
						11.23

(1) Approximately 60% of this was recovered from vehicle owners whose cars damaged the barrier.

This operational report covers a limited amount of experience which has been acquired during the year following initiation of the barrier construction program. Although there are indications regarding the effectiveness of the barriers, both in preventing cross-median head-on collisions and in increasing over-all accident rates, the experience so far should be interpreted with caution and only tentative conclusions should be made at this time. Additional data are being accumulated covering more extensive sections of barriers over a greater period of time. It is planned to continue the investigation. In the meantime, barriers are being installed on all 8- lane freeways and on freeways where the average daily traffic exceeds 60,000 per day. It has been shown in the 1959 study and confirmed by 1960 experience that four-fifths of all the cross-median, head-on fatal accidents occur on these high-volume freeways.

DISCUSSION OF OPERATIONAL FAILURES

Special detail studies were made from time to time of all accidents and in addition of each accident where vehicles passed over, went through, or climbed the barriers. These observations were made of accidents with all installations of the new designs of median barriers rather than only on the test sections.

Over-all, during the past year, three vehicles passed over new designs of barriers, three went through, and one came to rest on top of a barrier. The three crossovers all involved cable barrier. Two of these were the result of jumps due to causes unrelated to the cable barrier and therefore could have occurred over any 30 inch high barrier. One was the result of the vehicle hitting a curb and jumping high enough to clear the barrier cable. The second was a high speed vehicle which jumped over the barrier after leaving the road on the outside of a curve. The barrier in this case was placed in a low ditch section where the roadway had been rotated to provide for superelevation. This provided the car with an inclined ramp from which to jump.

The third crossover and also the case of the vehicle coming to rest on top of the barrier also occurred on cable-chain link designs. The cause was the same in both cases. The original cable barrier design called for a tension cable attached 9 inches above the ground, and that the chain link fabric be firmly clamped between the lower cable and the post. In both of these accidents and in many others resulting in only partial climbing, it was found that the vehicles approached at a low angle (less than 15 degrees) and high speed. Under these conditions of impact, a post and the firmly secured chain link fabric, combined with the lower cable, served as a ramp

for the front colliding wheel to get started in an upward direction. Such a start often elevated the automobile before the car body had an opportunity to penetrate the barrier far enough to provide for restraint by the top cable. Thus the car tended to ride the barrier down.

Two of the penetration type accidents involved trucks colliding with the blocked-out metal beam barrier and resulted in a complete failure of the system. The third penetration involved a small sports car hitting the cable barrier between posts at a high angle of collision and passing between the lower and upper cables. This car had a front end clearance of 29 inches and an over-all height of 33 inches, exclusive of the windshield.

A careful analysis of the above barrier crossovers indicates that they could be divided into two categories: one group that probably could be precluded by improvements in design and the other that reasonably could not be prevented by a physical barrier. For instance, in the case where the vehicle hit the curb, the car apparently jumped higher than the 30 inches necessary to clear the barrier cable. Since cars have been reported, as a result of accidents, to have jumped as high as 8 to 10 feet and in other cases to have cartwheeled, it would not be reasonable to build a barrier high enough to contain every chance accident that might occur.

Because of the required strength involved, it is also not considered practical to design a barrier that will effectively and completely resist the collision of the heaviest trucks. In the two failures on beam barriers that occurred during this past year, the barrier was completely destroyed within the collision area. However, in neither case did the truck penetrate more than a few feet onto the opposing roadway. In other words, even in failure the barriers provided sufficient resistance so as to reasonably contain the vehicles.

The third penetration was an accident unique to the cable barrier in that very small sports cars can penetrate below the top barrier cable under conditions where the angle of collision is relatively high (over 30 degrees). At smaller angles of collision it is probable that the fence post combined with the cable would still function as a positive barrier against penetration of this type of car.

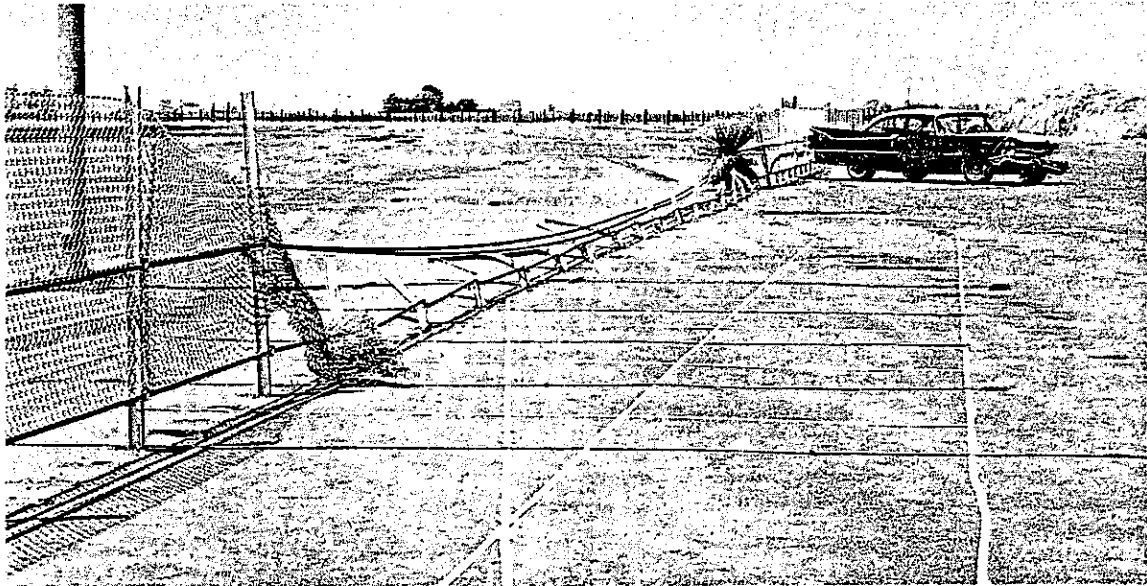
Analysis of the above failures indicated that the beam barrier was functioning about as well as could be expected; however, it appeared that further development work should be done on the cable barrier. Studies indicated that it should be possible to make improvements to prevent the tendency of cars to climb the barrier and also that it would be worthwhile to investigate the possible prevention of penetration by sports cars.

The accident in which the car jumped the barrier after leaving the outside of a curve showed that further information should be gathered concerning the effect of differences of grade and elevation on the trajectory of a moving vehicle. Such information could be used to determine the placement of a barrier.

Maintenance of the cable barrier showed certain improvements of details to be desirable. Most of the effort during maintenance was expended in replacing the posts and concrete footings, so this detail was worthwhile of redesign. With one exception, no problems were encountered in maintaining the cables. In one case of collision with the cable barrier, it was necessary to cut the cable so as to remove the vehicle (in this case the vehicle was a truck-trailer combination). This break was repaired by a cable splice using cable clamps and exercised no real problem.

CONTROLLED COLLISION TESTS

In order to develop details to correct the discussed failures, the following nine tests were performed. In addition to testing corrective details, certain substitute details were also tested. These included (1) alternate post footings, (2) highway guard rail type cable, (3) alternate cable turnbuckles, (4) cable splices, and (5) expanded metal light screen. Exhibit 3 (Appendix) shows the different footings tested and Exhibit 1 shows the over-all test site layout. Exhibits 4 through 12 list the pertinent facts concerning each test.



TEST NO. 1

Fabric: Chain link on impact side of barrier. Fabric under top cable but not contained under bottom cable.

Cables: 3 each 3/4 inch - 6 x 19 IWRC - 1 @ 9 inches and 2 @ 30 inches above pavement.

Post Footing: Type "A" 8 inch x 30 inch PCC (See Exhibit 3)

Purpose: To test current design for correlation with previous test series (1959). This test was also an attempt to duplicate the climbing that has occurred on the Ventura Freeway.

Performance: See Exhibit 4. Left front wheel raised 14 inches off pavement while climbing over lower cable. A slight yawing occurred near end of run with a violent 180° "spin out" approximately 100 feet from impact.

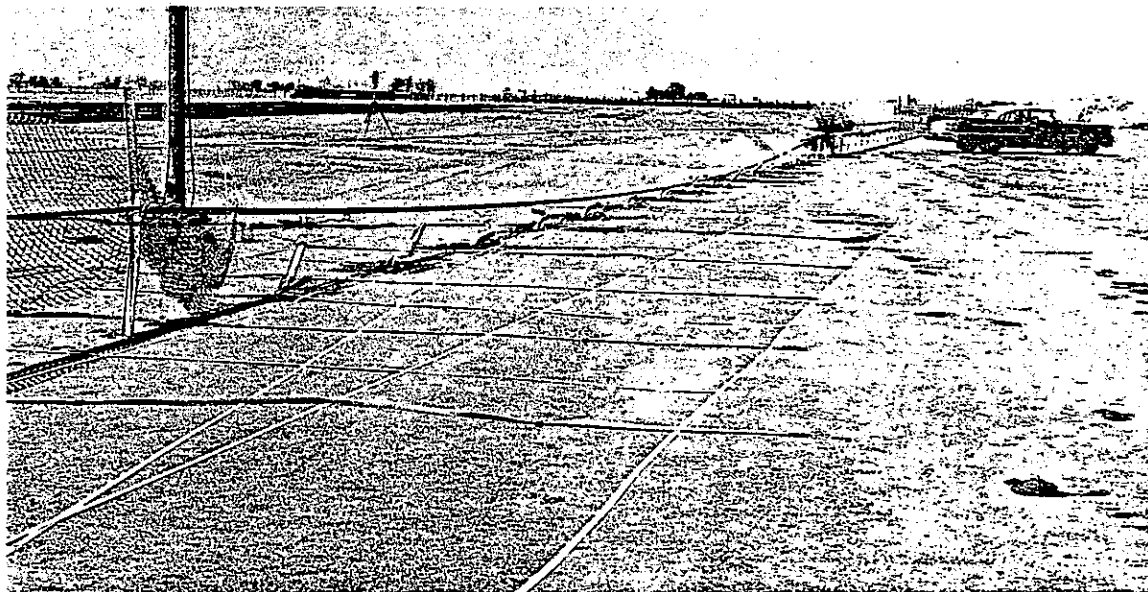
Maximum encroachment on traveled side: 21 feet.

Maximum encroachment on opposing side: 5½ feet.

Opposing side 4 foot or more encroachment for 6/10 seconds.

Opposing side 5 foot or more encroachment for 3/10 seconds.

Barrier Damage: Approximately 130 feet of mesh gathered up between top cables at point of spin-out. No cable fitting damage or failures. Damage was typical of that recorded during 1959 test series. Slight cracking of post footings was result of "green" concrete. No posts pulled out of footings. There was no appreciable movement of the post footings.



TEST NO. 2

Fabric: Chain link on impact side of barrier. "U" of cable clamp on impact side. Fabric contained under cable.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above pavement.

Post Footing: Type "A" 8 inch x 30 inch PCC (See Exhibit 3).

Purpose: To test current design with deletion of bottom cable.
All other parameters same as Test No. 1.

Performance: See Exhibit 5. All wheels remained on pavement throughout run. A slight yawing occurred 30 feet before a violent 280° "spin out" approximately 110 feet from impact.

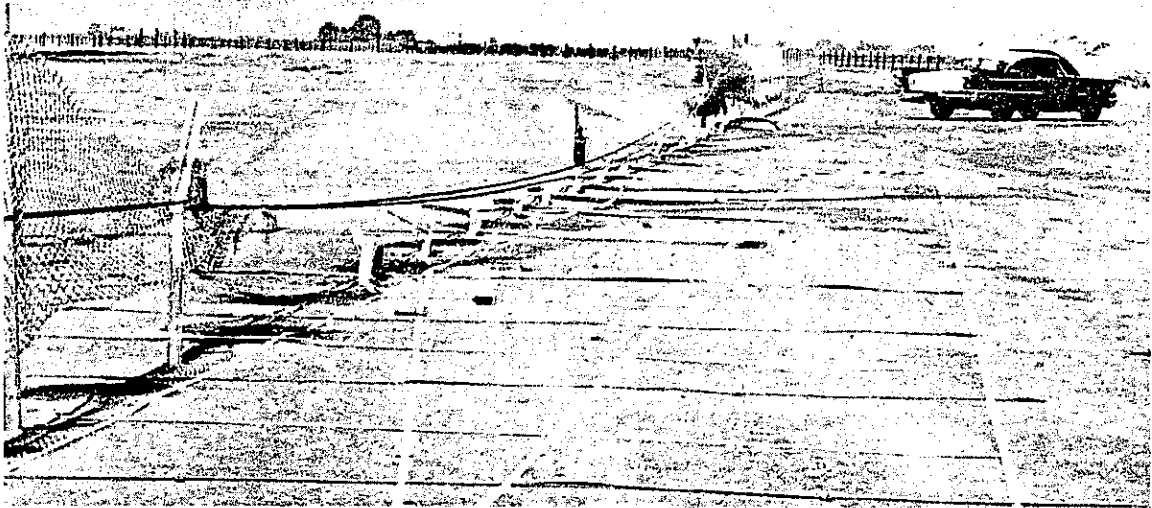
Maximum encroachment on traveled side: 29 feet.

Maximum encroachment on opposing side: 5½ feet.

Opposing side 4 foot or more encroachment for 6/10 seconds.

Opposing side 5 foot or more encroachment for 5/10 seconds.

Barrier Damage: Approximately 130 feet of mesh gathered up between cables at point of "spin out". Fabric and post damage was very similar to that of Test No. 1. Slight cracking of post footings was result of "green" concrete. No posts pulled out of footings. There was no appreciable movement of the post footings.



TEST NO. 3

Fabric: Chain link on impact side of barrier. "U" of cable clamp on impact side. Fabric contained under cable.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above pavement.

Post Footing: Type "D" Sheet Metal socket in PCC with 12 inch long wood wedge (See Exhibit 3).

Purpose: To test "2 cable" design with socket type post footings. All other parameters same as Test No. 2

Performance: See Exhibit 6. All wheels remained on pavement throughout run. No appreciable yawing. Violent 300° "spin-out" occurred approximately 125 feet from impact. Second post ahead of impact was pulled out of socket and carried down cables to point of "spin-out". Cable clamp was not completely stripped from post.

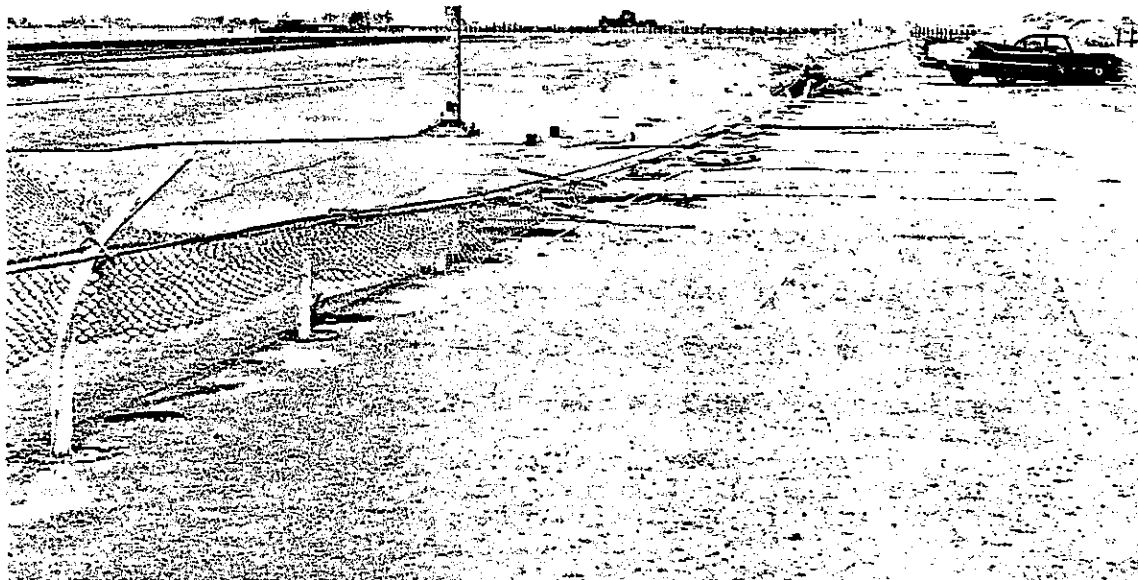
Maximum encroachment on traveled side: 23 feet.

Maximum encroachment on opposing side: 6 feet.

Opposing side 4 foot or more encroachment for 9/10 seconds.

Opposing side 5 foot encroachment for 6/10 seconds.

Barrier Damage: Approximately 125 feet of mesh gathered up between cables at point of spin-out. Fabric and post damage was very similar to that of Tests No. 1 and 2. One post pulled out of socket footing. Twenty posts pulled between 1/2 inch and 2 inches out of sockets. Slight cracking of footings was not severe enough to prevent re-use on Test No. 5.



TEST NO. 4

Fabric: Chain link and "U" of cable clamps on opposite side from impact. Fabric contained under cable.

Cable: 2 each 3/4 inch - 7 x 7 Highway Guard Cable @ 30 inches above pavement.

Post Footing: Type "C" 8 inch x 12 inch PCC (see Exhibit 3).

Cable Fittings: 2 each Type II Pipe Turnbuckles with swaged pulls located 100 feet ahead of point of impact.

Purpose: To compare with Tests No. 1, 2, and 3, the effect of collision with fabric fastened on opposite side from impact. To compare retention efficiency of 12 inch deep post footing with that of the 30 inch post footing. To compare susceptibility to jamming of cable clamps on pipe type turnbuckle with previous (1959) tests on Type I drop forged turnbuckles (see Exhibit 2).

Performance: See Exhibit 7. All wheels remained on pavement until spin-out. Fabric and clamps jammed at turnbuckle, tearing entire front fender off vehicle. Violent 270° "spin out" at 115 feet from impact. During first part of spin, left side of car raised 18 inches. Right front of car tore next to last post out of footing and stripped it from the cables. No yawing occurred during run.

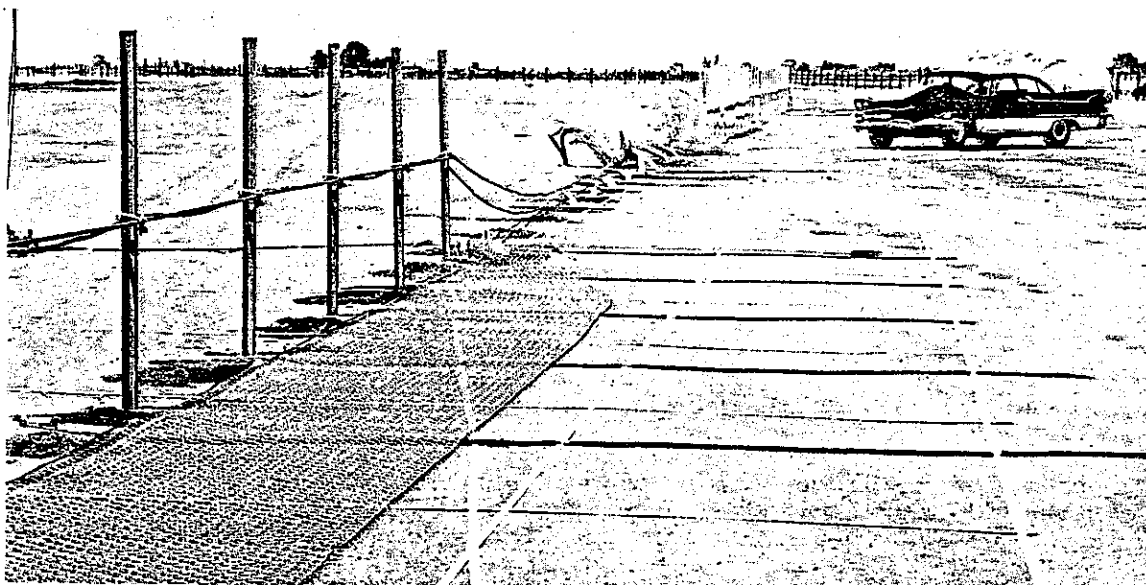
Maximum encroachment on traveled side: 19 feet.

Maximum encroachment on opposing side: 6 feet.

Opposing side 4 foot or more encroachment for 5/10 seconds.

Opposing side 6 foot or more encroachment for 1/10 seconds.

Barrier Damage: Approximately 90 feet of fabric gathered up between cables at point of "spin out". There was no failure of the turnbuckles; however, the cable was badly kinked adjacent to the cable pull on the front turnbuckle (impact side) and also 10 feet ahead of point of spin-out where post had pulled out of footing. Footing failure and cracked footings were result of "green" concrete.



TEST NO. 5

Fabric: Chain link on impact side of barrier. "U" of cable clamps on opposite side. Fabric not contained by cable.

Cable: 2 each 3/4 inch - 7 x 7 Highway Guard Cable @ 30 inches above pavement.

Post Footing: Type "D" Sheet metal socket with 3/4 inch x 2 inch x 24 inch wood wedges. (See Exhibit 3).

Cable Fittings: 2 each Type II Pipe Turnbuckles located 50 feet (impact side) and 58 feet (opposite side) ahead of point of impact. Pre-formed dead-end on each cable 100 feet behind point of impact.

Purpose: Repeat test on Type II Pipe Turnbuckles with fabric outside of cable not contained by cable or clamps. Also a repeat test on the socket type post footing with a longer wood wedge in an attempt to retain posts in sockets.

Performance: See Exhibit 8. Car started "spin-out" approximately 70 feet from point of impact due to posts #2 and #3 pulling out of sockets and jamming at the second turnbuckle located 58 feet ahead of impact. Posts, clamps and fabric passed over first turnbuckle located 50 feet ahead of impact and jammed on second turnbuckle. The vehicle carried entire bundle 10 feet further as dead-end located 100 feet behind point of impact failed. Fabric fastened with 12 gage steel tie wires was torn from posts for 70 feet behind point of impact and fell to pavement.

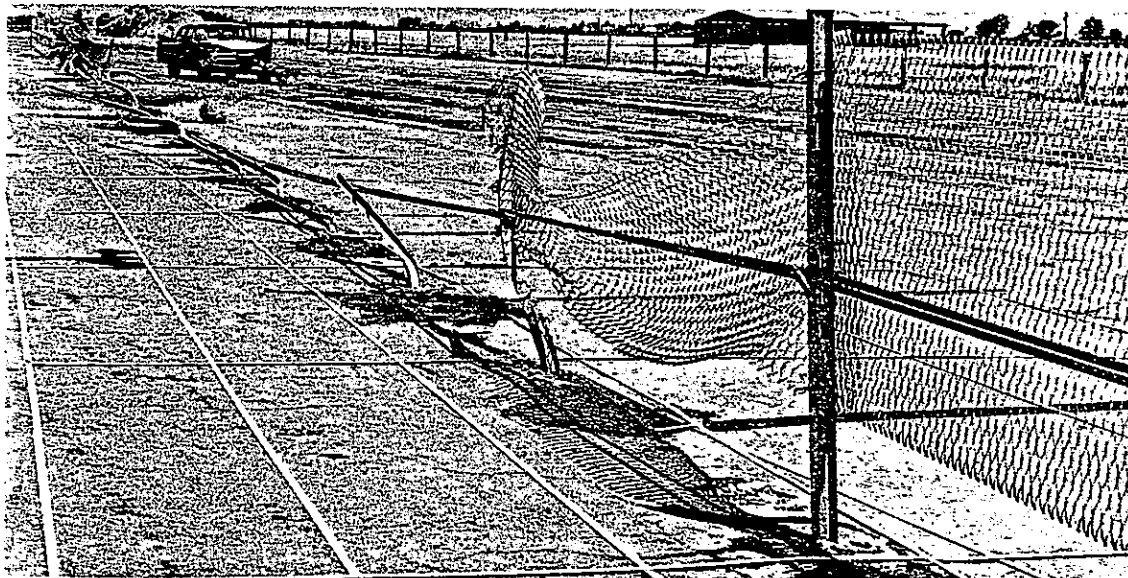
Maximum encroachment on traveled side: 24 feet.

Maximum encroachment on opposing side: 7 feet.

Opposing side 4 foot or more encroachment for 5/10 seconds.

Opposing side 6 foot or more encroachment for 2/10 seconds.

Barrier Damage: Preformed dead-end failed under extreme loading caused by posts and clamps jamming on turnbuckle. The dead-end had been removed from a cable used on a previous installation. During removal, a critical amount of aluminum oxide coating was stripped from the inside of the weave resulting in insufficient friction for the assembly to retain the cable under normal collision loads. Socket type post footings from Test No. 3 were re-used for this test. No additional cracking was noted.



TEST NO. 6

Fabric: Expanded steel mesh on impact side of barrier. "U" of cable clamp on impact side. Fabric not contained by cables. Fabric 18 gage galvanized steel, 1.33 inch x 3 inch diamond, 8 foot 4 inch x 42 inch panels.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above pavement.

Post Footing: Type "C" 8 inch x 12 inch PCC (see Exhibit 3).

Purpose: To test effectiveness during collision of expanded metal fabric compared to previous tests on chain link fabric. Also a re-test on the 8 inch x 12 inch concrete collar type post footing.

Performance: See Exhibit 9. All wheels remained on pavement throughout run with a very slight yawing of vehicle. Post No. 11 pulled out of footing; however, there was no measurable change in vehicle reaction when compared to Test No. 2 on 8 inch x 30 inch PCC footings. The expanded metal fabric reacted very similarly to chain link fabric under identical collision conditions. Very smooth deceleration to 160° spin-out at approximately 80 feet from impact.

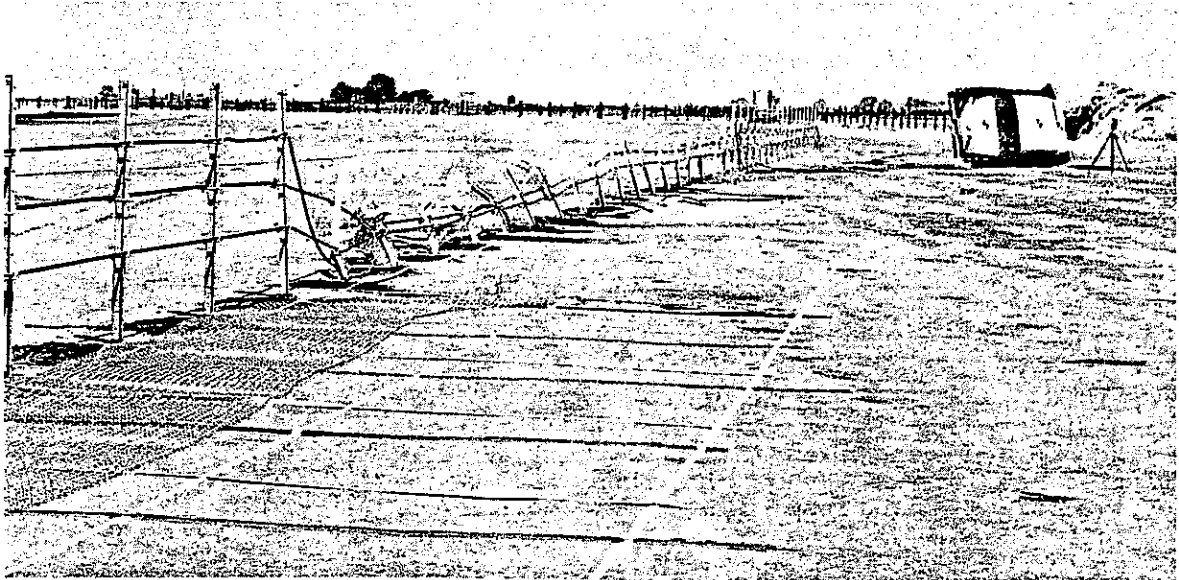
Maximum encroachment on traveled side: 18 feet.

Maximum encroachment on opposing side: 6 feet.

Opposing side 4 foot encroachment for 4/10 seconds.

Opposing side 5 foot encroachment for 3/10 seconds.

Barrier Damage: Fourteen panels (112 feet) of expanded metal gathered up at point of spin out. The severe cracking of all post footings in the collision zone and complete failure of one was due to "green" concrete.



TEST NO. 7

Fabric: Chain link on impact side of barrier. Fabric not contained by cable. "U" of clamp on impact side.

Cable: 3 each 3/4 inch - 6 x 19 IWRC @ 20 inches, 32 inches, and 44 inches above pavement.

Post Footing: Type "D" sheet metal socket in PCC with 3/4 inch x 2 inch x 24 inch wooden wedges. Voids filled with 200-300 pen. asphalt. (See Exhibit 3)

Cable Fittings: 3 each preformed cable splices 125 feet ahead of point of impact.

Purpose: To compare the efficiency of 3 cables at different heights with that of the preceding tests on 2 cables at the same height. To test the retention of the posts in sockets by the addition of paving asphalt.

Performance: See Exhibit 10. The vehicle crossed the two bottom cables approximately 10 feet from point of impact and was retained by the top cable for 130 feet. All wheels were clear of the pavement for 80 feet. At a point 100 feet from impact, the vehicle was nose down on the left front wheel, rolling to an angle of 45 degrees and yawing to the left at a 30° angle. High speed data films show evidence that the compressed tire and spring of the front suspension, added to the lateral energy stored in the deflected cable, was impetus for the final roll of the vehicle in a direction opposite to that attained at the point of spin out.

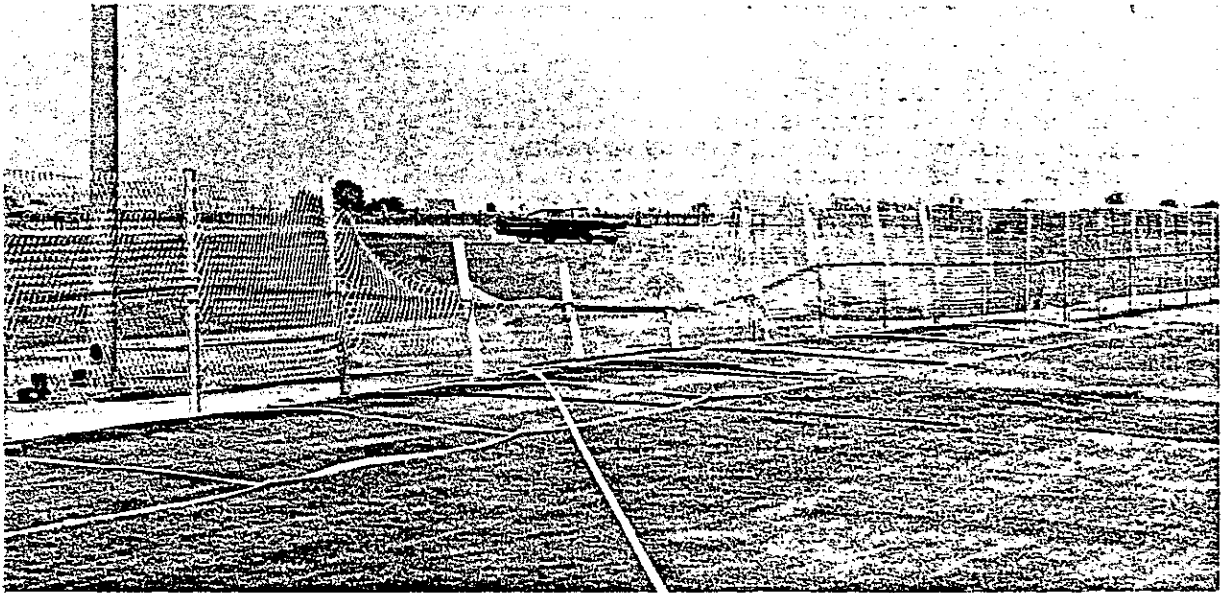
Maximum encroachment on traveled side: 18 feet.

Maximum encroachment on opposing side: 5½ feet.

Opposing side 4 foot encroachment for 1-1/10 seconds.

Opposing side 5 foot encroachment for 1/10 seconds.

Barrier Damage: The preformed cable splice located 125 feet ahead of impact failed as the windshield post sliding along the cable passed the frayed ends of the splice. At this location, the failure had no appreciable effect on the vehicle reaction; however, had the splice been installed 20 feet closer to the point of impact, the vehicle would have rolled over the barrier as the splice released.



TEST NO. 8

Fabric: Chain link on impact side of barrier. "U" of cable clamps on impact side. Fabric not contained by cables.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above slope grade, 18 inches above crown of ramp.

Post Footing: Type "B" sheet metal socket with 200-300 pen. asphalt. (See Exhibit 3)

Cable Anchor: 3 foot diameter x 2 foot deep PCC.

Top Tension Wire: 7 gage spring steel wire 57 inches above slope grade.

Purpose: To test for retention of vehicle on a simulated 8 degree super-elevated curve with 6:1 side slope in the median.

Performance: See Exhibit 11. The vehicle left the crown of the ramp and traveled airborne 17 feet to point of impact. Data films show that the vehicle had dropped only 2 inches along the trajectory from the crown of the ramp to the barrier. At the point of impact, the cables were below the center of the bumper at an effective height of 20 inches. The bumper contacted the post forcing it back and down and the cable was carried down with the post. The left front tire contacted the barrier at an intersection of post and cable further forcing the cable down and rolling over with no tendency to snag. As the vehicle progressed across the barrier each wheel was successively forced into its wheel well. There was no tendency for any part of the vehicle to snag on the cables. The 7 gage tension wire cracked the top of the windshield before failing at the 3/8 inch turnbuckle located 150 feet behind the point of impact.

Barrier Damage: Post collision height of cables at point of impact was approximately 8 inches above the crown elevation of the simulated super. No post footings were cracked.



TEST NO. 9

Fabric: Chain link on impact side of barrier. "U" of cable clamps facing impact. Fabric not contained by cable.

Cable: One 3/4 inch - 6 x 19 IWRC @ 30 inches above crown of superelevated ramp. Cable on impact side of barrier.

Post Footing: Type "B" sheet metal socket filled with 200-300 pen. asphalt (see Exhibit 3)

Cable Anchor: 3 foot diameter x 2 foot deep PCC.

Tension Wire: 7 gage spring steel @ 58 inches above crown of ramp.

- Purpose:
1. To retest vehicle retention on an 8% superelevated curve by moving the barrier constructed for Test No. 8 to within 1 foot of the crown and placing the cable at 30 inches above a horizontal projection of the superelevation crown.
 2. To determine the encroachment on the opposing side when barrier is constructed with a single cable.
 3. To test the efficiency of the single cable envelope barrier design as a possible alternate method of construction on superelevated curves having a sloped center drainage ditch.

Maximum encroachment on traveled side: 16 feet

Maximum encroachment on opposing side: 12 feet

Opposing side 10 foot encroachment for 4/10 seconds: Measured from centerline of front cable.

Opposing side 2 foot encroachment for 2/10 seconds: Measured from centerline of rear cable.

Performance: At point of impact the cable made contact with the vehicle between the headlight and bumper and was contained in the fender over the front left wheel as it progressed through collision. The vehicle continued level and airborne as it left the ramp in a trajectory similar to that of Test No. 8 for approximately 20 feet. The snubbing action of the cable forced the front of the car down just prior to contact with the rear cable in the envelope design. The vehicle continued through collision snubbed nose-down by the front and rear cables through the transition of single cables to double cables with a very smooth deceleration to 180° spin-out at approximately 130 feet from point of impact.

Barrier Damage: 125 feet of fabric was gathered up at point of spin out. Seven post footings were cracked due to "green" PCC. None of the posts were moved from the asphalt filled sockets.

DISCUSSION OF CONTROLLED TESTS

A crossover type of accident considered to be intolerable is where the vehicle climbs the side of a cable barrier and knocks it down as the vehicle passes on over. This type of accident is unique to the cable barrier. As stated previously, analysis of this type of crossover indicated that it was the result of a deficiency in the details of design rather than in the basic flexible barrier concept. Controlled collision tests for the purpose of analyzing these deficiencies were made at flat angles and high speed; first on the original design (Test No. 1), altered only by moving the chain link fabric outside the lower cables, and then by elimination of the lower cable entirely as in all tests following No. 1, except Test No. 7.

Elimination of the chain link fabric from the lower cable clamps resulted in an improvement in the action. However, high speed moving pictures revealed that the lower cable alone gave the left front end of the car an upward impetus as the front colliding wheel passed over the junction of the cable and the post. Thus under certain circumstances it would be possible for the car to continue on upward. Removal of the lower cable resulted in penetration of the barrier by the vehicle with no tendency toward upward movement and no loss in barrier action. Post collision investigation of details of the damaged test barriers indicated that the elimination of the lower cable resulted in no loss of barrier effectiveness but did cause a slight loss in stiffness of the system behind the collision. However, any barrier damage due to this loss of rigidity was insignificant.

One of the original design considerations in placing the lower cable in the system was that it would serve to trap the car in the

median area as it attempted to return to the onside roadway at the end of the collision path. Operation experience showed that at a flat angle of collision, whether or not the lower cable was in position, the car tended to spin at the end of the collision path back into the traveled lane. This was verified by test collisions. A review of the accident reports from both the Nimitz and the Santa Ana test sections indicated that this vehicle reaction was typical of a majority of the collisions that occurred on the freeway and that in no case had a secondary collision resulted from this spin out.

Two other details of construction were tested and adopted as a result of these studies. The original design called for a standard turnbuckle every 500 feet along the cable. Since the smoothness of deceleration of the colliding vehicle with the cable-chain link barrier depends primarily upon the friction brake effect of the cable clamps stripping from the posts, it is important that this action proceed unhindered if possible. It was found (Test No. 4) that when the test collision vehicle progressed along the cable through a turnbuckle, the clamps and the contained mesh jammed at the turnbuckle. This resulted in an abrupt deceleration and violent "spin out" of the colliding vehicle. This defect was also illustrated by the General Motors³ tests of 1960.

Tests No. 4 and 5 were made to judge the effect of repositioning chain link fabric outside the cables. This design eliminated binding while at the same time the removal of the chain link to the outside of the cable had no appreciable effect on the rate of deceleration of the car.

As was originally anticipated, the cable-chain link barrier on the Nimitz and Santa Ana test sections were subjected to a great deal of collision damage. The Maintenance Department found the most

costly single item was the removal and replacement of the steel posts and their concrete footings. In addition to replacing the concrete and post, it was necessary for the posts to set in the new footings for at least 24 hours before the cable and chain link could be rehung on the post. This required two trips under heavy traffic conditions. It was decided that, if economically feasible, a post socket design or an otherwise modified footing could solve this problem.

Two designs were developed and successively tested. One was a concrete collar around the upper one foot of the footing and the second a socket in a full depth footing. In the first the principle was that the earth below the collar would furnish support for the barrier while the collar was curing. Thus the barrier fabric and cable could be re-erected immediately.

In two test collisions, the concrete collar type of footing was used and in five the socket type.

The collar type of footing proved adequate. However, several of the footings broke during collision. It was therefore necessary to remove the concrete piecemeal before backfilling the hole and re-drilling for the new footing. While this design proved adequate, it is considered practical only for locations where the soil is fairly tight and free of rocks.

Several methods of holding the posts in the sockets were considered. Among these were the use of steel wedges, bolts, set screws, wood wedges, sand (plain and also topped with sulphur), sulphur, and asphalt. All were discarded in favor of asphalt. However, it was considered necessary to determine the minimum restraint needed to keep the post in place during collision. Therefore tests were made using an oversize socket with the posts held in place only with wooden wedges (Tests No. 3 and 5). In each of these two tests at least one post pulled out.

Analysis of the pictures indicates that during the early part of a collision, the posts are subjected to a substantial vertical force. Sufficient resistance must be offered to prevent uplift of the posts during this period of vertical loading.

These two tests proved that wooden wedges alone provided insufficient resistance. Therefore since sand has little or no internal resistance, it also was discarded. Steel wedges, through-bolt or set screws, could be made to work but were discarded because of cost and possibility of jamming. Sulphur would also work but was discarded because of potential corrosion in addition to the difficulty of cleanout or reheating of the sulphur during repair.

After completing tests using wooden wedges alone, the sockets were filled with asphalt which in Tests No. 7, 8, and 9 proved to be adequate. Tests No. 8 and 9 utilized sockets which fit the posts but the socket for Test No. 7 was oversized with the space taken up by a wooden wedge. Grade 200-300 paving asphalt was chosen. Asphalt proved able to resist the shock loading with no movement. At the same time the damaged post could be removed by a slow pull and a new post placed by slow pressure. In a controlled laboratory test, it was found that a pull of 700 pounds was necessary to remove a post from an asphalt filled socket when tested at 0° F. It took one minute to complete the removal.

Of particular interest are Tests No. 8 and 9. Here a cross-section of highway found on many California freeways was simulated in which an 8% superelevation intersected a 6:1 sloped center drainage ditch. Actual barrier installations have been placed in the center of the ditch which is coincident with the center line of the freeway median area, with the thought that the cars on a collision course would follow the 6:1 side slope down to the barrier. Test No. 8 showed that when the barrier was 6 feet away from the edge of the shoulder at the bottom of the simulated ditch, the car traveling at a 20° angle of collision would pass on over the barrier. After a

study of the car's trajectory this was remedied in Test No. 9 by duplicating the previous test conditions but moving the barrier up the slope of the ditch to within one foot of the edge of the simulated shoulder, thus giving the car an opportunity to penetrate the barrier and become engaged under the cable.

Analysis of the trajectory of the car in the pictures of Test No. 8 indicates that a barrier to be effective should be placed no lower than 27 inches above a horizontal projection from the top edge of an approaching 8% grade. This is about the maximum superelevation that will be encountered in roads which justify the use of median barriers. The best solution for this condition is to place the barrier at the top or before the top of the superelevation. If it is necessary to place the barrier on the ditch side of the cross-slope, then the barrier cable should be no lower than 27 inches above the crown nor higher than 33 inches above the ground surface.

Test No. 6 utilized expanded steel mesh in lieu of chain link fabric. No difference in barrier action was noted. However, first cost and maintenance costs of the expanded fabric will be markedly higher than for the chain link fabric. This is due primarily to the higher first cost of the expanded metal but will also be affected by the fact that this material is furnished at present only in short panels.

In Tests No. 4 and 5 the use of 7 x 7 highway guard cable was substituted for the 6 x 19 IWRC cable usually used. This 7 x 7 cable was more difficult to handle during repairs and placement. In addition its cross-section did not lend itself to proper adjustment during the tightening of the cable to post clamps. In general these tests seemed to indicate that the cross-section and relative stiffness of the 7 x 7 cable to the 6 x 19 cable make the latter cable more desirable for use as a flexible barrier member.

TEST PROCEDURE AND INSTRUMENTATION OF TEST COLLISIONS

With the exception of the type of the cars and speed and angle of approach, this series of tests was conducted in the same manner as the full scale tests reported in 1960 (see Reference 1).

So as to more nearly simulate the type of accident that seemed to cause problems with the cable barrier, heavier cars (over 4000 pounds) driven at higher speeds (over 80 mph) and colliding at flatter angles (10° or less) were used.

Since this series of tests were designed to test refinements of design rather than the over-all effectiveness of the barriers, the instrumentation was not as complex as that previously used. Decelerations were determined from an analysis of the high speed data films rather than from decelerometers mounted in the vehicle and the dummy.

The anthropometric dummy was unrestrained, and his movements through collision were observed by a high speed data camera mounted inside the vehicle.

The photographic instrumentation was approximately as used previously, except that the following cameras were used rather than those listed in the previous test¹. The below listed 16 mm data cameras gave 100% reliability rather than the 25 to 50% reliability obtained in the past:

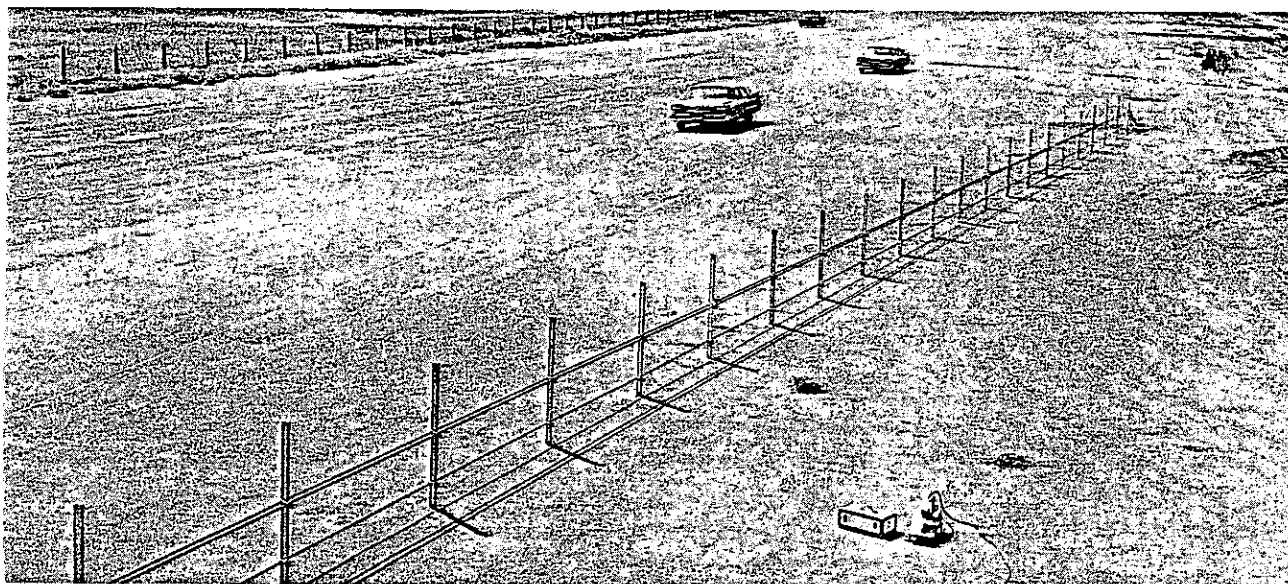
<u>Camera Number</u>	<u>Type</u>	<u>Frame Rate</u>	<u>Lens</u>	<u>Location</u>
1	Fastax	1200	12.5mm	100 feet behind barrier
2	Photosonics	400	12.5mm	Tower covering pre- impact
3	Photosonics	400	12.5mm	Tower covering impact

<u>Camera Number</u>	<u>Type</u>	<u>Frame Rate</u>	<u>Lens</u>	<u>Location</u>
4	Photosonics	400	12.5mm	Tower covering post impact
5	Photosonics	400	4 in.	Rear ground mount
6	Photosonics	400	4 in.	Front ground mount
7	Photosonics	400	12.5mm	In crash vehicle
8	Photosonics	400	1 in.	Rear platform

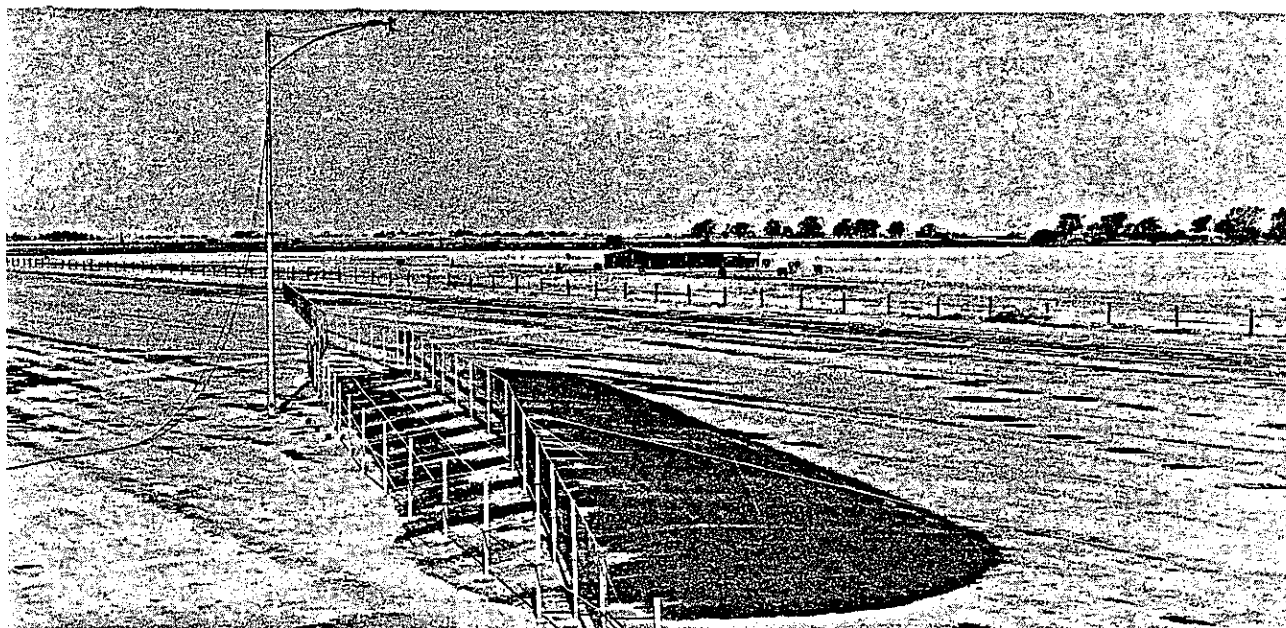
In addition to the above 16mm cameras, one Bolex and one Bell & Howell 24 frames/sec. cameras were placed at various locations for documentary coverage. All sequence pictures shown in the exhibits were recorded with a 70mm Hulcher Mod. 20 camera at a 20 frames/sec. rate.

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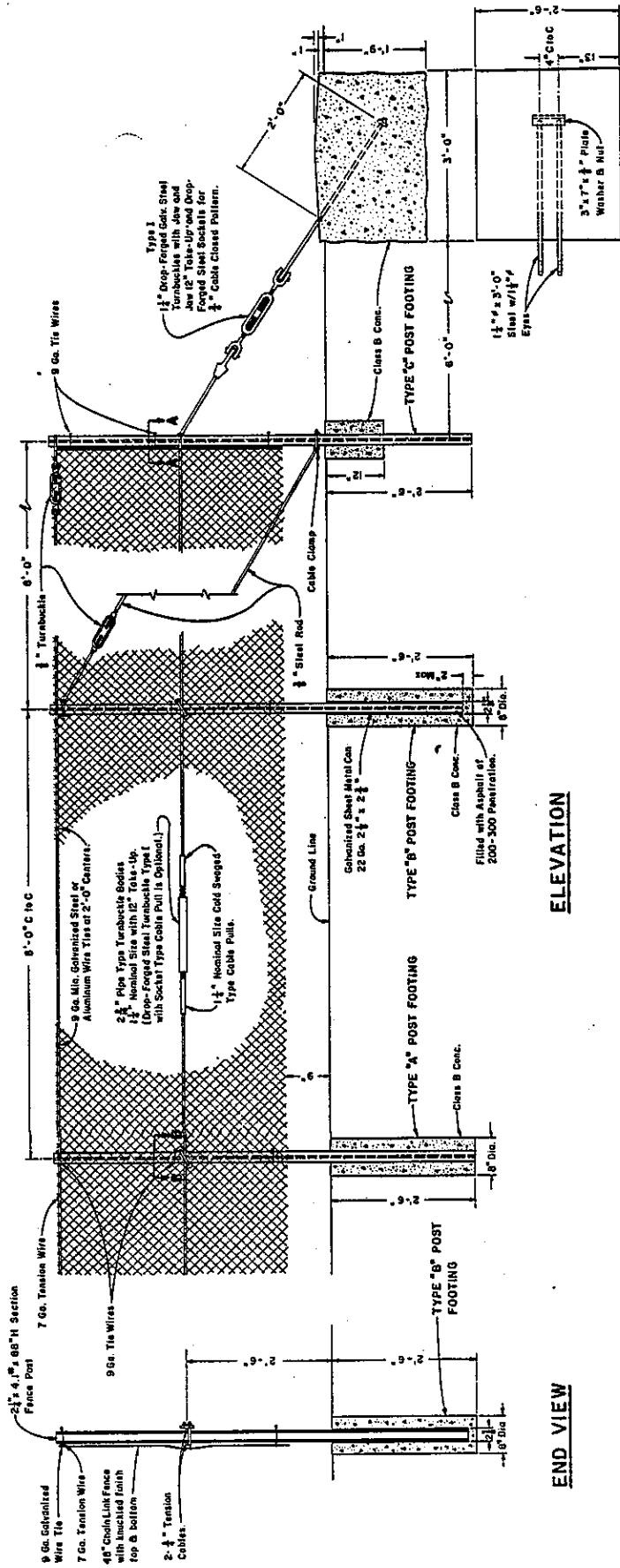
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W. G. Cichowski
General Motors Report No. PG-12387



View of 7 degree collision course showing crash vehicle followed by control car. Chain link fabric was deleted from the first 200 ft. on the 600 ft. installations. Ground mounted data camera is in right foreground.



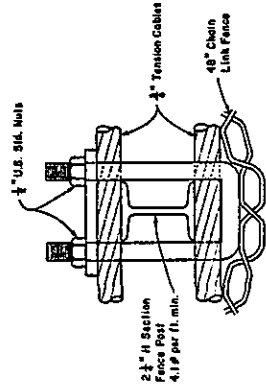
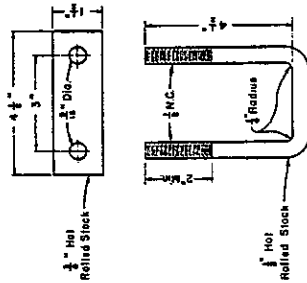
View of typical photographic instrumentation installation showing data camera tower, ground grid and guide tape intersecting point of impact at 20 degrees.



ANCHOR BLOCK PLAN

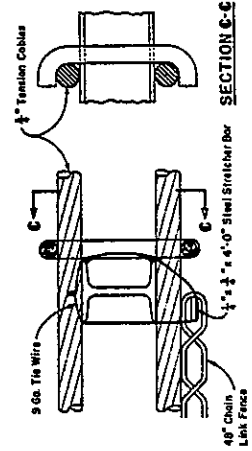
ELEVATION

END VIEW



VIEW B - B

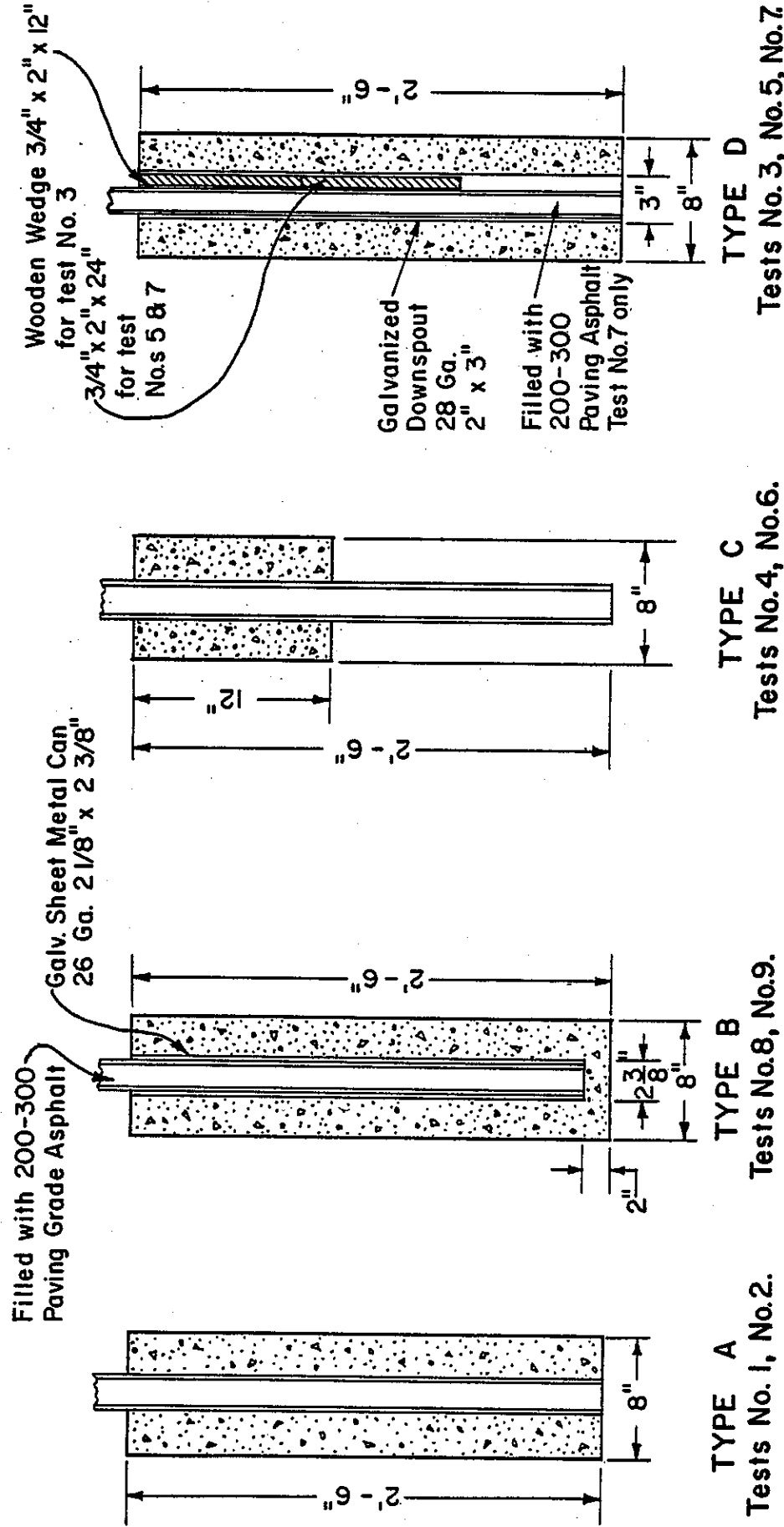
LINE POST ASSEMBLY



VIEW A - A

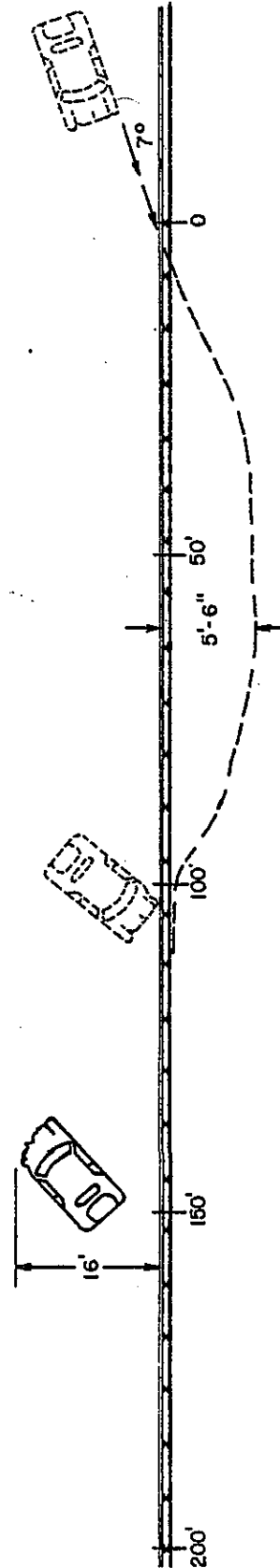
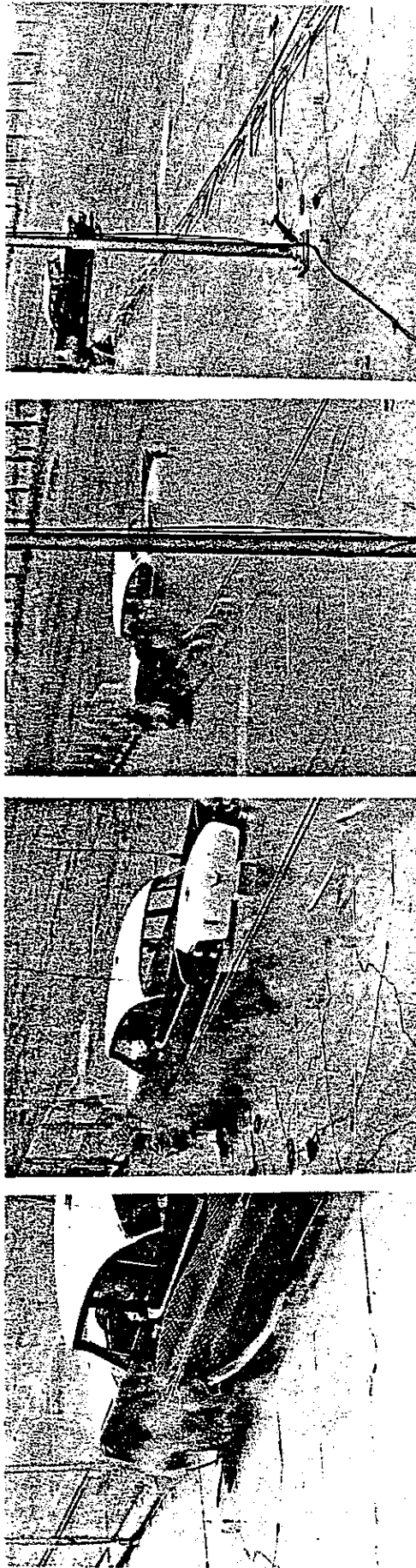
END POST ASSEMBLY

STATE OF CALIFORNIA		DIVISION OF HIGHWAYS	
MATERIALS & RESEARCH DEPARTMENT		PROPOSED CABLE-CHAIN LINK	
BARRIER DESIGN		C-355	
DATE	DESIGNED BY	CHECKED BY	APPROVED BY
12-1-61	Robert W. Fells	John L. Euston	
BY	IN CHARGE	PER	DATE
			12-1-61



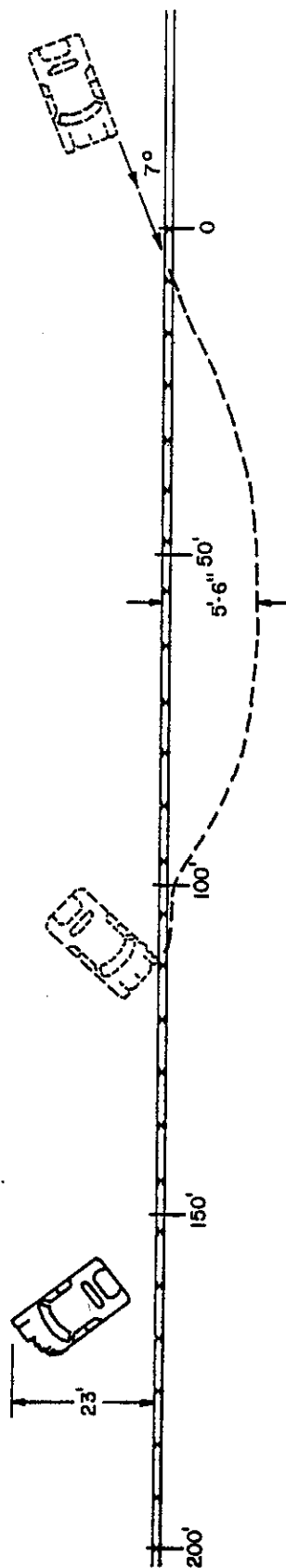
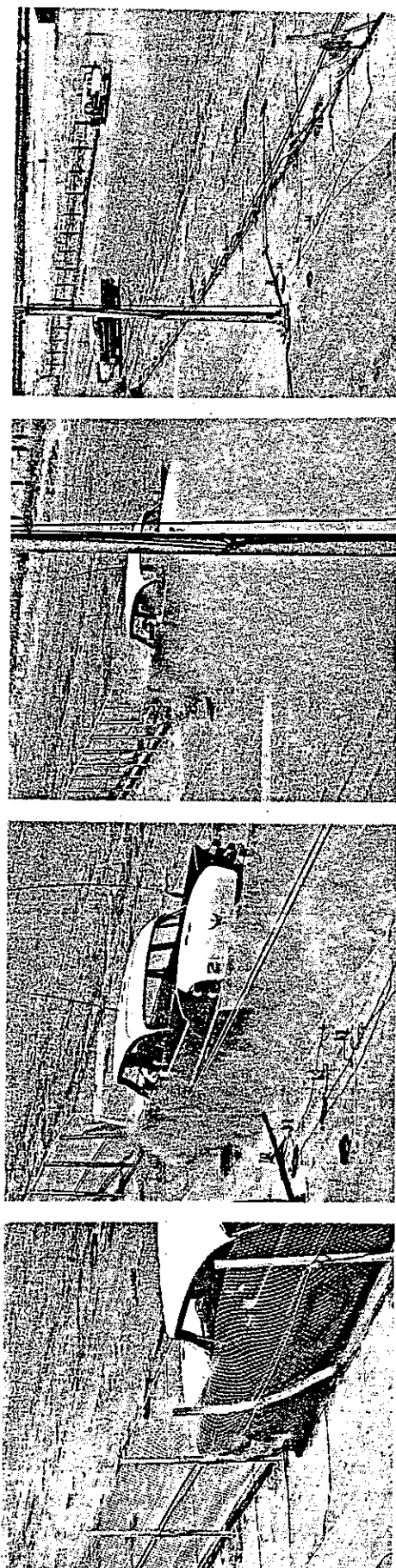
NOTE: CLASS B CONCRETE USED FOR ALL TYPES

POST FOOTING DETAILS



FENCE	48" chain.	FENCE DAMAGE	152' damaged
	link at 9" above pavement.	CABLE FITTING DAMAGE	none
CABLE	3/4" 6x19 IWRC 1	CABLE DAMAGE	none
	at 9" and 2 at 30" above pavement.	POST DAMAGE	19 damaged
POST FOOTING	Design A	POST FOOTING DAMAGE	7 cracked
POST SPACING	8' O.C.	MAX DYNAMIC DEFLECTION OF CABLES	5 1/2
LENGTH OF INSTALLATION	600'	VEHICLE DECELERATION (PEAK LONG)	6.5g's
GROUND CONDITION	Dry	VEHICLE DAMAGE	\$ 350

TEST NO. 1
 DATE 6-8-61
 VEHICLE Dodge 59 Sedan
 SPEED 78 MPH
 IMPACT ANGLE 7°
 VEHICLE WEIGHT 4300 lbs.
 (W/DUMMY & INSTRUMENTATION)



FENCE 48" chain
link at 9" above pavement.
CABLE 3/4" 6 x 19
IWRC 2 at 30" above pavement.
POST FOOTING Design A
POST SPACING 8' O.C.
LENGTH OF INSTALLATION .. 600'
GROUND CONDITION Dry

FENCE DAMAGE 140' damaged
CABLE FITTING DAMAGE none
CABLE DAMAGE slight fraying
POST DAMAGE 19 damaged
POST FOOTING DAMAGE 12 cracked
MAX. DYNAMIC DEFLECTION OF CABLES .. 6'
VEHICLE DECELERATION (PEAK LONG.) .. 2.4 g's
VEHICLE DAMAGE \$ 350

TEST NO. 2

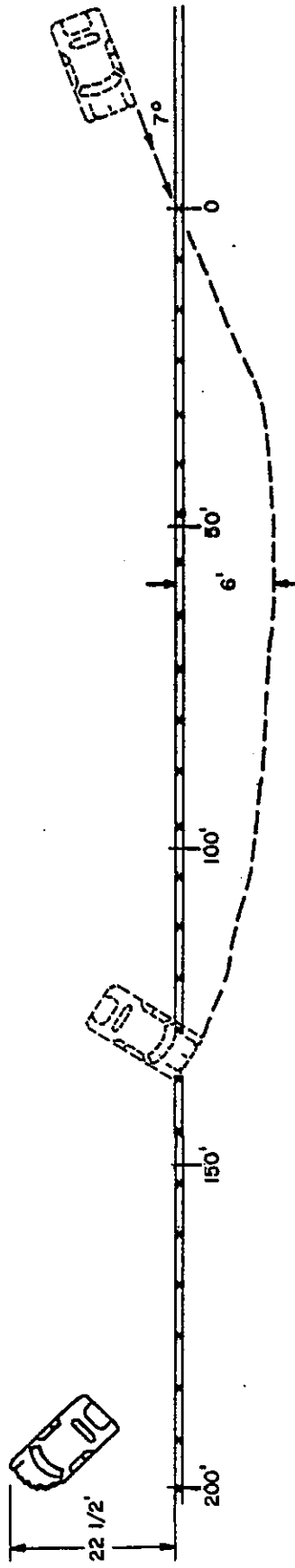
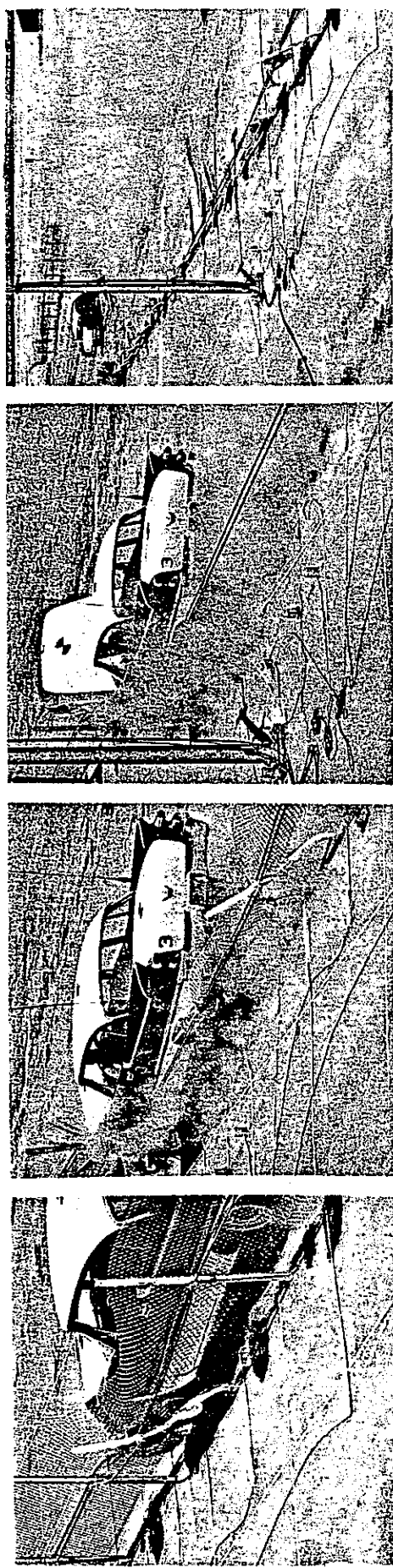
DATE 6-13-61

VEHICLE Dodge 59 Sedan

SPEED 84 MPH

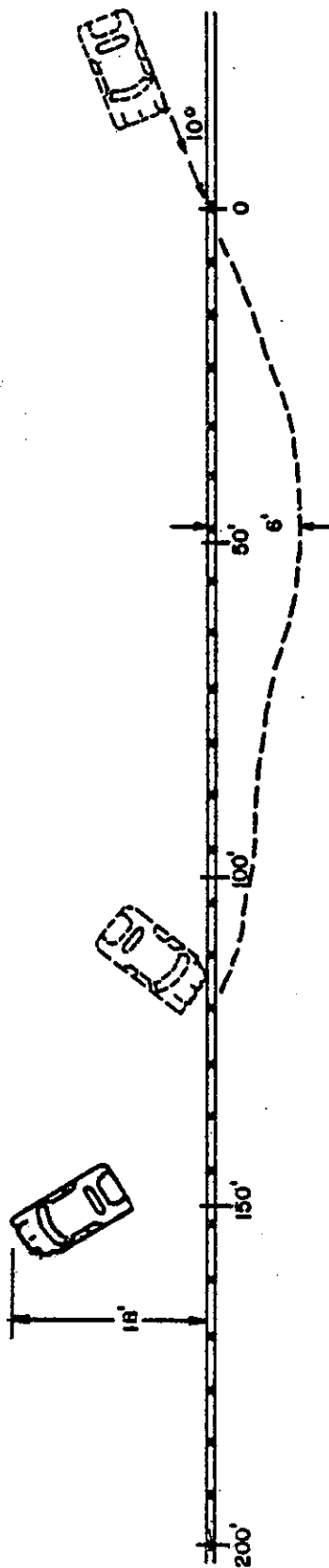
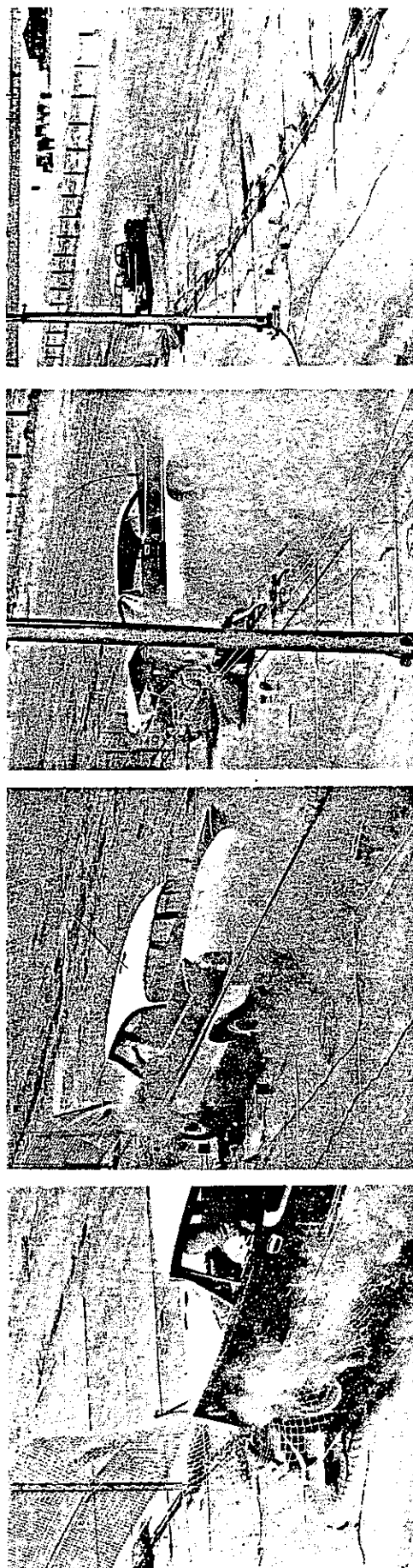
IMPACT ANGLE 7°

VEHICLE WEIGHT 4300 lbs.
(w/DUMMY & INSTRUMENTATION)



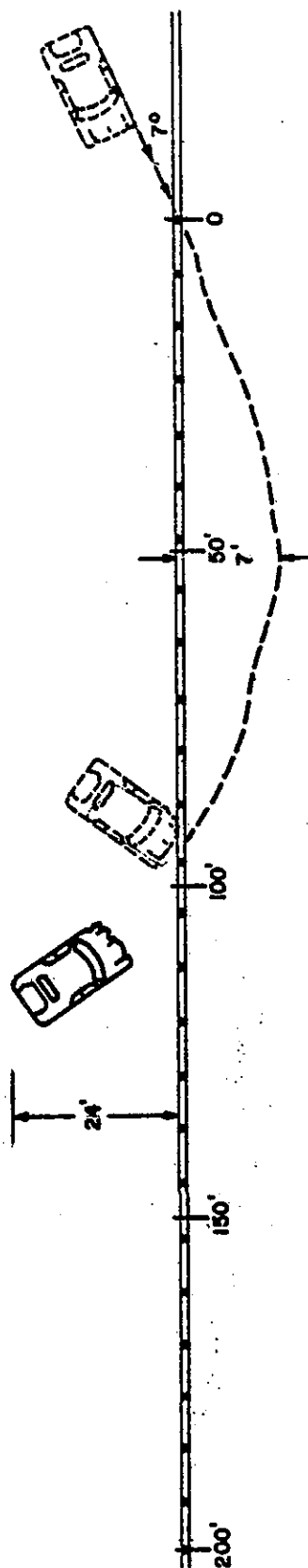
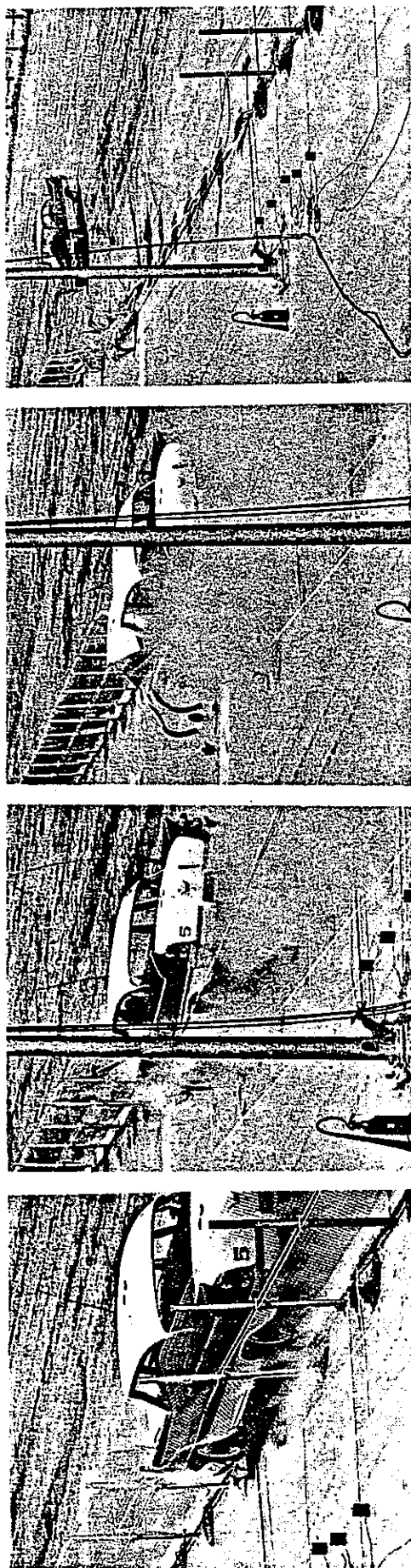
FENCE.....	48" Chain link	FENCE DAMAGE.....	152' Damaged
	at 9" above pvmf.	CABLE FITTING DAMAGE.....	None
CABLE.....	3/4" 6 x 19	CABLE DAMAGE.....	None
	WRC 2 at 30" above pavement.	POST DAMAGE.....	20 Damaged - 1 Pulled Out
POST FOOTING.....	Design D	POST FOOTING DAMAGE.....	5 Cracked
POST SPACING.....	8' O.C.	MAX. DYNAMIC DEFLECTION OF CABLES.....	6'
LENGTH OF INSTALLATION.....	600'	VEHICLE DECELERATION (PEAK LONG).....	4 G's
GROUND CONDITION.....	Dry	VEHICLE DAMAGE.....	\$ 350

TEST NO.....	3
DATE.....	6-19-61
VEHICLE.....	Dodge 59 Sedan
SPEED.....	86 M.P.H.
IMPACT ANGLE.....	7°
VEHICLE WEIGHT.....	4300 lbs.
(W/DUMMY & INSTRUMENTATION)	



FENCE.....	48" chain link at 9" above pavement.	FENCE DAMAGE.....	136' damaged	TEST NO.....	4
CABLE.....	3/4" 7 x 7 2 at 30" above pavement.	CABLE FITTING DAMAGE.....	1 turnbuckle slightly bent	DATE.....	6-26-61
POST FOOTING.....	Design C	CABLE DAMAGE.....	none	VEHICLE.....	Dodge 59 Sedan
POST SPACING.....	8' O.C.	POST DAMAGE.....	17 damaged--1 pulled out	SPEED.....	76 MPH
LENGTH OF INSTALLATION.....	600'	POST FOOTING DAMAGE.....	16 cracked--1 failed	IMPACT ANGLE.....	10°
GROUND CONDITION.....	Dry	MAX DYNAMIC DEFLECTION OF CABLES.....	.6'	VEHICLE WEIGHT... 4300 lbs.	
		VEHICLE DECELERATION (PEAK LONG).....	3.6 g's	(W/DUMMY & INSTRUMENTATION)	
		VEHICLE DAMAGE.....	\$700		

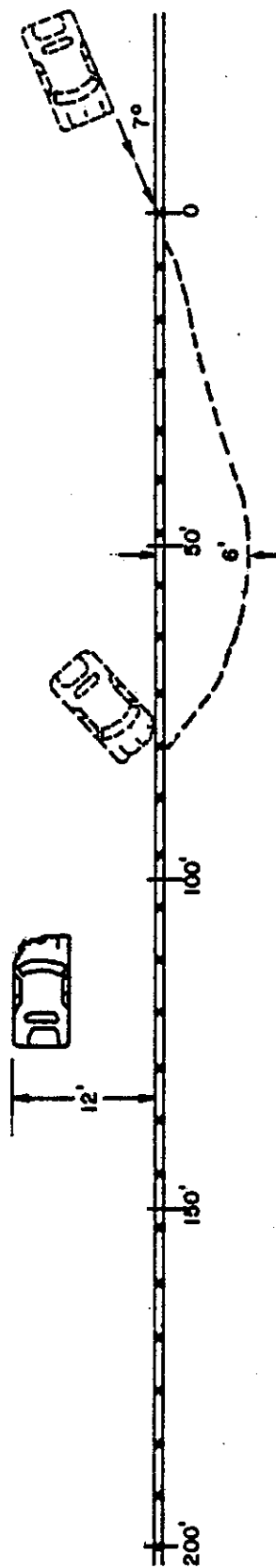
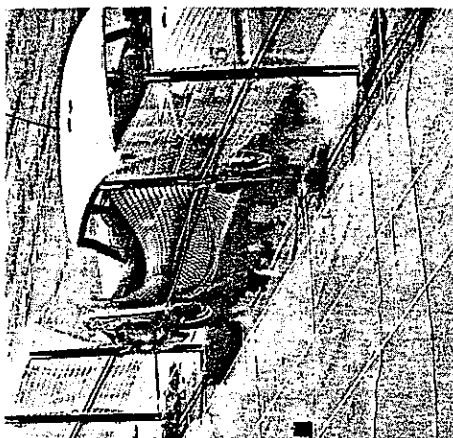
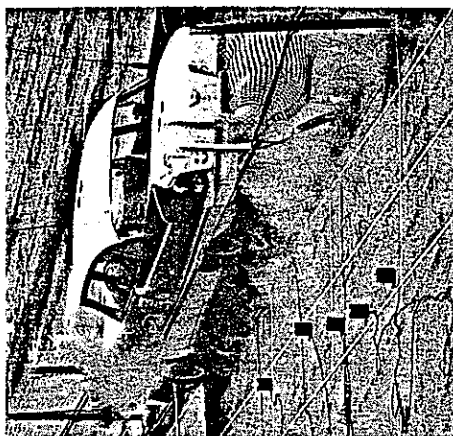
STATE OF CALIFORNIA -- DIVISION OF HIGHWAYS -- MATERIALS & RESEARCH DEPT.



FENCE..... 48" chain link at
9" above pavement.
CABLE..... 3/4" 7 x 7.2 at
30" above pavement.
POST FOOTING..... Design D
POST SPACING..... 8' O.C.
LENGTH OF INSTALLATION.. 600'
GROUND CONDITION..... Dry

FENCE DAMAGE..... 112' damaged
CABLE FITTING DAMAGE..... 1 deadend failed
CABLE DAMAGE..... none
POST DAMAGE..... 15 damaged-2 pulled out
POST FOOTING DAMAGE 10 cracked
MAX. DYNAMIC DEFLECTION OF CABLES.. 7'
VEHICLE DECELERATION (PEAK LONG).. 4.8 g's
VEHICLE DAMAGE..... \$ 350

TEST NO..... 5
DATE..... 6-30-61
VEHICLE..... Dodge 59 Sedan
SPEED..... 84 MPH
IMPACT ANGLE..... 70
VEHICLE WEIGHT... 4300 lbs.
(W/DUMMY & INSTRUMENTATION)



FENCE... 42" 18 ga. steel expanded metal
1.35" x 3" diamond at 15" above part.
CABLE... 3/4" 6x19 WRC 2
at 30" above pavement.
POST FOOTING... Design C
POST SPACING... 6' O.C.
LENGTH OF INSTALLATION .600'
GROUND CONDITION... Dry

FENCE DAMAGE... 136' expanded metal damaged

CABLE FITTING DAMAGE... none

CABLE DAMAGE... none

POST DAMAGE... 16 damaged, 1 pulled out

POST FOOTING DAMAGE... 15 cracked, 1 failed

MAX. DYNAMIC DEFLECTION OF CABLES... 6'

VEHICLE DECELERATION (PEAK LONG)... 3 g's

VEHICLE DAMAGE... \$350

TEST NO. 6

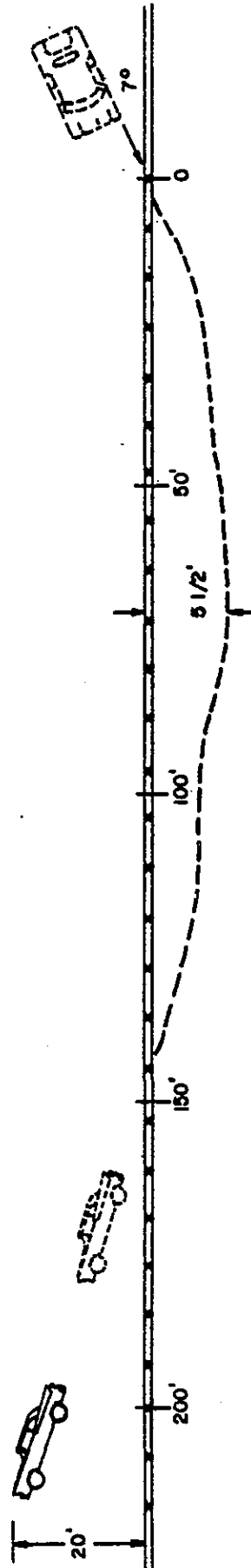
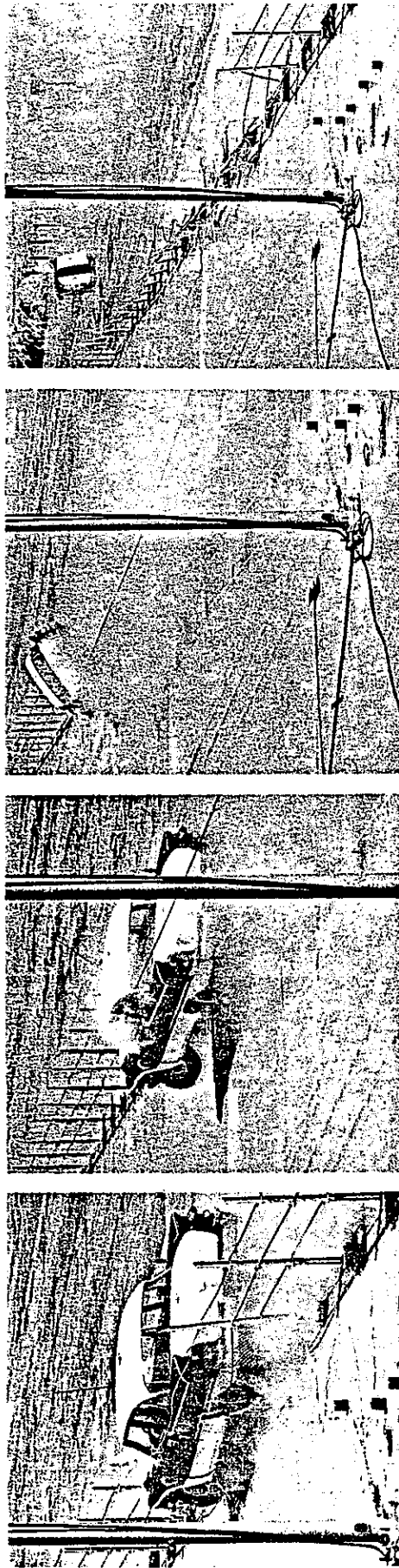
DATE... 7-10-61

VEHICLE... Dodge 59 Sedan

SPEED... 75 MPH

IMPACT ANGLE... 7°

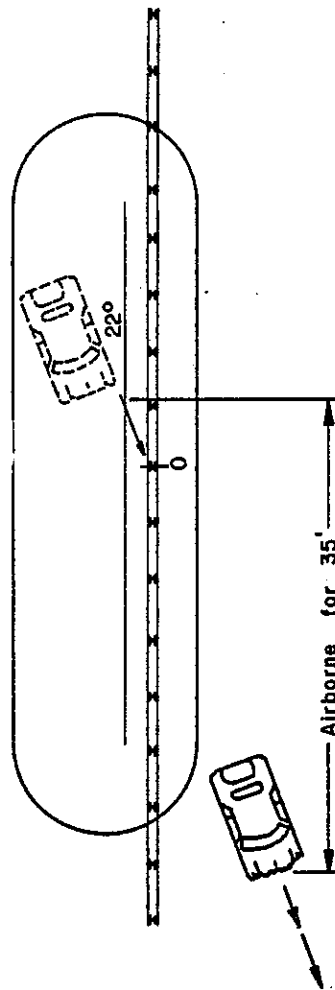
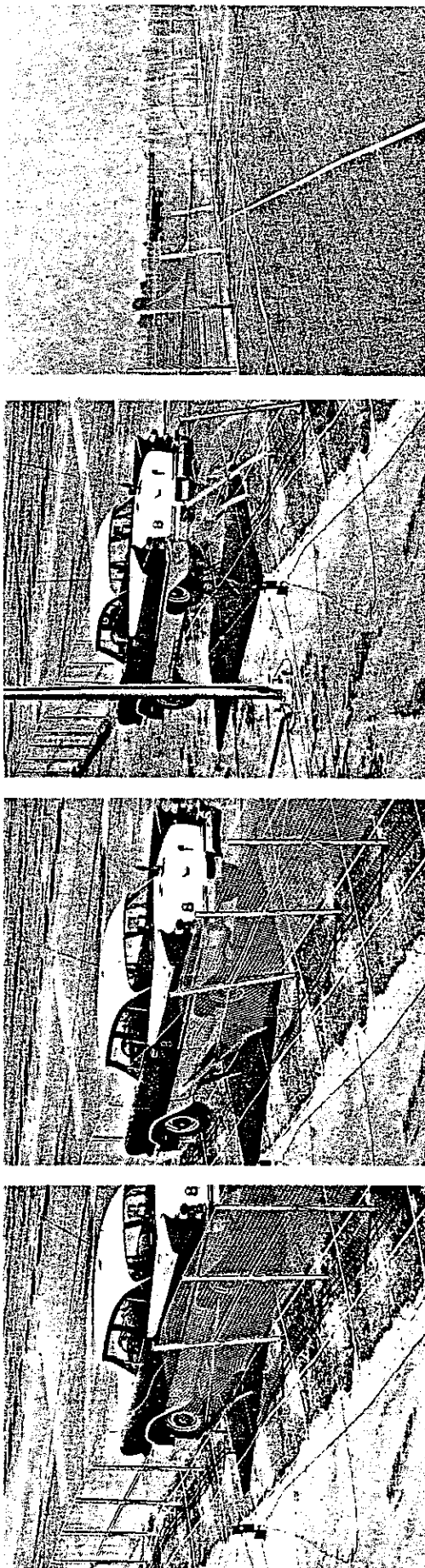
VEHICLE WEIGHT... 4300 lbs.
(W/DUMMY & INSTRUMENTATION)



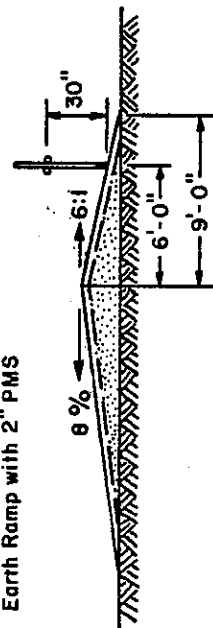
FENCE.....48" chain link at
9" above pavement.
CABLE.....3/4" 6 x 19 JWRc 3 at
20" 32" and 44" above pavement
POST FOOTING.....Design D
POST SPACING.....8' O.C.
LENGTH OF INSTALLATION . 600'
GROUND CONDITION.....Dry

FENCE DAMAGE.....184' damaged
CABLE FITTING DAMAGE.....preformed splice failed
CABLE DAMAGE.....none
POST DAMAGE.....19 damaged
POST FOOTING DAMAGE.....12 cracked
MAX. DYNAMIC DEFLECTION OF CABLES . 5 1/2'
VEHICLE DECELERATION (PEAK LONG) . 6.8 g's
VEHICLE DAMAGE.....Total loss

TEST NO.....7
DATE.....7-14-61
VEHICLE.....Dodge 59 Sedan
SPEED.....77 MPH
IMPACT ANGLE.....7°
VEHICLE WEIGHT... 4300 lbs.
(W/DUMMY & INSTRUMENTATION)



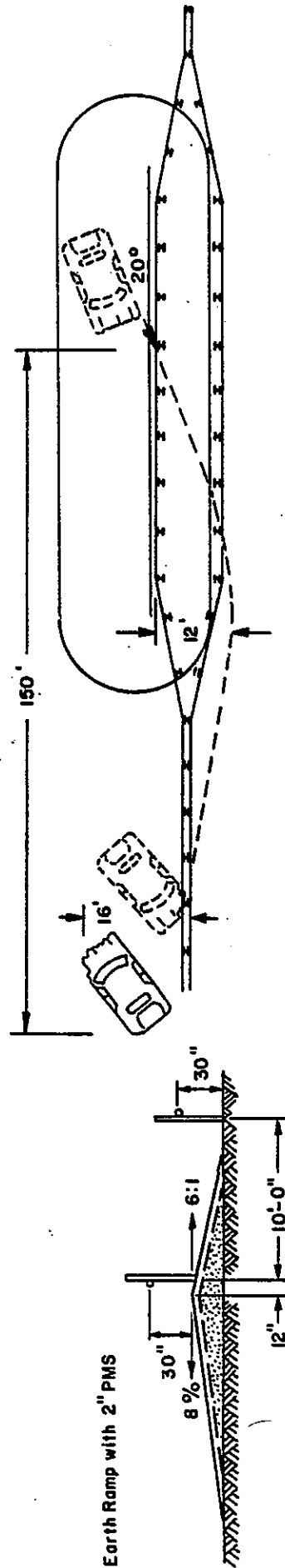
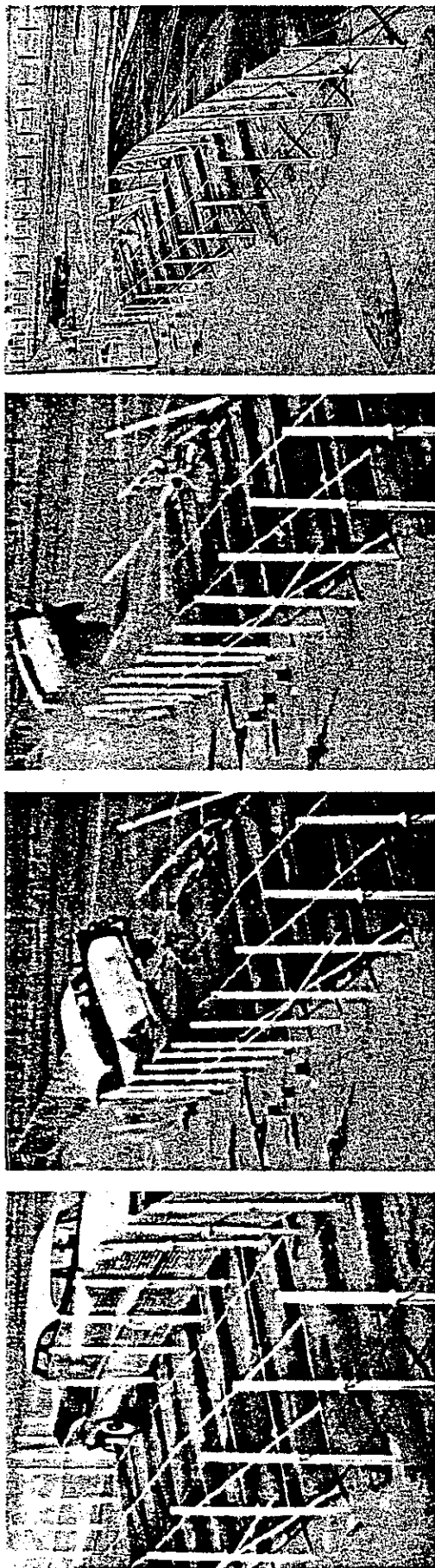
Earth Ramp with 2" PMS



FENCE 48" Chain link at 9" above pavement.
 CABLE 3/4" 6x19 IWRC 2 at 30" above pavement.
 POST FOOTING Design B
 POST SPACING 8' O.C.
 LENGTH OF INSTALLATION... 400'
 GROUND CONDITION Dry

FENCE DAMAGE 35' damaged
 CABLE FITTING DAMAGE none
 CABLE DAMAGE none
 POST DAMAGE 7 damaged
 POST FOOTING DAMAGE none
 MAX. DYNAMIC DEFLECTION OF CABLES... Vehicle jumped barrier
 VEHICLE DECELERATION (PEAK LONG.) ... 1.7 G's (at end of jump)
 VEHICLE DAMAGE \$ 150

TEST NO. 8
 DATE 8-18-61
 VEHICLE Dodge 59 Sedan
 SPEED 74 MPH
 IMPACT ANGLE 22°
 VEHICLE WEIGHT ... 4300 lbs.
 (W/DUMMY & INSTRUMENTATION)



FENCE.....	48" chain link at 9" above pavement.	FENCE DAMAGE	136' damaged	TEST NO.....	9
CABLE.....	3/4" 6 x 19 IWRC 2 at 30" above pavement.	CABLE FITTING DAMAGE.....	none	DATE.....	9-29-61
POST FOOTING.....	Design B	CABLE DAMAGE.....	none	VEHICLE.....	Dodge 59 Sedan
POST SPACING.....	8' O.C.	POST DAMAGE.....	22 damaged - 11 slightly bent	SPEED.....	82 MPH
LENGTH OF INSTALLATION.....	400'	POST FOOTING DAMAGE.....	7 anchors cracked	IMPACT ANGLE.....	20°
GROUND CONDITION.....	Dry	MAX. DYNAMIC DEFLECTION OF CABLES.....	12'	VEHICLE WEIGHT.....	4300 lbs.
		VEHICLE DAMAGE.....	\$ 750	(W/DUMMY & INSTRUMENTATION)	